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# DEVELOPMENT OF THEORIES OF COLLECTIVE AND COGNITIVE SKILL RETENTION

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# Abstract

Conducting the right amount of training is critical and a scientific basis for scheduling refresher or maintenance training is required. While some scientific literature exists on scheduling of individual training on procedural tasks, the CF operates at an organisational level with an increasing high level of technology and with a growing emphasis on cognitive tasks. This paper reviews published and unpublished data and theory from the military research and development community pertaining to the retention of collective and cognitive skills as a step toward fielding a validated model of collective and cognitive skill retention. Electronic sources and an international panel of scientists were consulted to collect available data for review. Review of the selected material revealed five factors: task variables, structure of the collective, collective membership, individual differences, and training. Only one developed model of collective skill retention was found. This model was reviewed in conjunction with other models related to retention of individual skills. None are broad enough in scope in terms of the factors covered or sufficiently well validated to serve as a satisfactory foundation for predicting retention of collective performance. A plan for developing a model of collective skill retention is proposed.

# Résumé

Il est crucial d'offrir le bon degré de formation, et il faut donc une base scientifique pour l'établissement des calendriers des cours de recyclage ou de maintien. Il existe certains écrits scientifiques sur l'établissement de calendriers pour la formation individuelle portant sur des tâches procédurales, mais les FC fonctionnent au niveau organisationnel, en faisant appel à une technologie toujours plus perfectionnée et en accordant de plus en plus d'importance aux tâches cognitives. Cet article passe en revue les données et théories publiées et non publiées provenant du milieu de la recherche et du développement militaires et portant sur la préservation des compétences collectives et cognitives en tant qu'étape menant à la proposition d'un modèle validé de maintien des compétences collectives et cognitives. On a consulté des sources électroniques et un groupe international de scientifiques en vue d'identifier les données disponibles pour la recension. L'analyse de la documentation sélectionnée a révélé l'existence de cinq facteurs : les variables des tâches, la structure du collectif, les membres du collectif, les différences individuelles et la formation. On n'a relevé qu'un modèle détaillé de maintien de compétences collectives. Ce modèle a été analysé de pair avec d'autres modèles associés au maintien de compétences individuelles. Aucun n'a une portée suffisamment vaste en termes de facteurs pris en compte ou n'est suffisamment validé pour servir de fondement à la prévision du maintien du rendement collectif. Un plan d'élaboration d'un modèle de maintien des compétences collectives est proposé.

# Executive Summary

This review was conducted under the direction of Defence Research and Development Canada – Toronto. Within the ultimate goal of fielding a validated model to be used by military personnel to schedule training of collective tasks, the purpose of this project was to review publications from the military research and development community concerning retention of collective and cognitive skills. Contributions from the general scientific literature were also considered.

The report is organized around sections considering training in the military; the nature of collectives and collective tasks; development and retention of collective performance; factors affecting retention of collective performance; existing models of collective performance; and recommendations for a way ahead.

A broad range of factors with the potential to affect retention of performance on collective tasks was considered. These factors were categorized as those affecting the collective task and its sub-tasks, collective structure, the collective membership, individual differences, and the type of training provided before and during the retention interval on the task of interest and others.

A brief review and discussion of the general literature on team work, team mental models and organizational issues suggests that retention of performance on individual sub-tasks will be strongly related to retention of overall collective performance – particularly with respect to co-ordination. Individual sub-tasks include both those performed in isolation by collective members and sub-tasks requiring interaction among collective members. The effect of these individual sub-tasks on overall collective performance will depend on their criticality and level of interdependence with respect to the overall collective task, and the need for information exchange and interaction with other collective members. Understanding the relationships among sub-tasks within particular collective tasks for particular collective structures is a pre-requisite of effective study of retention of collective performance, and requires selection or development of a suitable team task analysis approach.

Only one developed model of collective skill retention was found as a result of the literature search. This model was reviewed in conjunction with other models related to retention of individual skills. The conclusion was drawn that while these models form a good conceptual point of departure, none are broad enough in scope in terms of the factors covered or sufficiently well validated to serve as a satisfactory foundation for predicting retention of collective performance. Particular areas of omission included transfer from other training during the retention interval, experience of team members, internal turbulence and external turnover, and shared team mental models.

The term "collective" was rarely found in the literature on training and its use appears to add little to terms such as team and organization, already in common use. It is recommended that the literature on team and organizational issues be more thoroughly reviewed with respect to the issues contained in this report. In particular, the literature on team mental models should be considered in greater detail in relation to retention issues, including retention of knowledge contributing to team performance.

To fulfil the global goal of developing an effective decision support tool for unit planners and modelling retention of team performance under conditions typical of military training, a longitudinal study of a small number of contrasting collectives and collective tasks is recommended. This should be based on analysis of both the needs of unit training planners and the team tasks involved in the collective tasks chosen.

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# Sommaire

Cette analyse a été effectuée sous la direction de l'IMED (Institut de médecine environnementale pour la défense). Le but ultime étant de proposer un modèle validé pouvant être utilisé par le personnel militaire pour planifier la formation se rapportant aux tâches collectives, ce projet visait à passer en revue les publications du domaine de la recherche et du développement militaires portant sur le maintien de compétences collectives et cognitives. On a également pris en considération des ouvrages scientifiques généraux.

Le compte rendu est divisé en sections portant sur: la formation dans le secteur militaire; la nature des collectifs et des tâches collectives; le perfectionnement et le maintien d'un rendement collectif; les facteurs influant sur le maintien d'un rendement collectif; les modèles existants de rendement collectif; et les recommandations quant à la voie à suivre.

On a pris en considération un vaste éventail de facteurs susceptibles d'influer sur le maintien du rendement dans l'exécution de tâches collectives. Ces facteurs ont été répartis en catégories: ceux qui influent sur les tâches collectives et leurs sous-tâches, la structure du collectif, les membres du collectif, les différences individuelles et le type de formation offerte avant et pendant l'intervalle de maintien à l'égard de la tâche visée et d'autres tâches.

Une brève étude et analyse de la littérature générale sur le travail d'équipe, sur les modèles mentaux d'équipes et sur les questions organisationnelles donnent à penser que le maintien du rendement dans l'exécution de sous-tâches individuelles est étroitement lié au maintien du rendement collectif global – particulièrement en ce qui a trait à la coordination. Les sous-tâches individuelles incluent à la fois celles qui sont exécutées isolément par les membres d'un collectif et celles qui nécessitent une interaction entre les membres d'un collectif. L'effet de ces sous-tâches individuelles sur le rendement collectif global dépend de leur criticité et du degré d'interdépendance par rapport à la tâche collective globale, ainsi que du besoin d'échange d'information et d'interaction avec d'autres membres du collectif. Il faut au préalable comprendre les liens entre les sous-tâches de tâches collectives particulières dans des structures collectives particulières pour pouvoir bien étudier le maintien du rendement collectif, ce qui nécessite la sélection ou la mise au point d'une méthode convenable d'analyse des tâches d'équipe.

La revue de la littérature n'a permis de découvrir qu'un modèle détaillé de maintien des compétences collectives. Ce modèle a été examiné parallèlement à d'autres modèles de maintien des compétences individuelles. On en est arrivé à la conclusion que, même si ces modèles constituent un point de départ conceptuel intéressant, aucun n'a une portée suffisamment vaste en termes de facteurs pris en compte ou n'est suffisamment bien validé pour servir de fondement à la prévision du maintien du rendement collectif. Les lacunes ont été observées particulièrement dans les domaines suivants: les échanges entre activités de formation au cours de l'intervalle de maintien, l'expérience des membres des équipes, les perturbations internes et le roulement externe, ainsi que les modèles mentaux communs des équipes.

Le terme «collectif/collective» a rarement été relevé dans la littérature sur la formation et son emploi ne semble pas ajouter beaucoup à des termes comme «équipe» et «organisation» déjà couramment utilisés. Il est recommandé d'examiner plus à fond la littérature sur les équipes et les organisations, sous l'angle des points soulevés dans ce compte rendu. Il faudrait surtout étudier plus attentivement la littérature sur les modèles mentaux des équipes par rapport à l'aspect du maintien, et notamment du maintien des connaissances contribuant au rendement des équipes.

Pour atteindre l'objectif global, qui est d'élaborer un bon outil d'aide à la décision à l'intention des planificateurs d'unités et de modéliser le maintien du rendement d'équipe dans des conditions

caractéristiques de la formation militaire, il est recommandé d'effectuer une étude longitudinale sur un petit nombre de collectifs et de tâches collectives divergents. Il faudrait à cette fin se fonder sur l'analyse des besoins des planificateurs de la formation des unités ainsi que des tâches d'équipe composant les tâches collectives choisies.

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# 1. Introduction

This project was conducted under the direction of Defence Research and Development Canada – Toronto by Human*systems*® Incorporated under Standing Offer contract W7711-0-7694, let on 1st January 2002 and completed on March 31st 2002.

The Canadian Forces (CF) has large and ongoing requirement to train. Conducting the right amount of training is critical and a scientific basis for scheduling refresher or maintenance training is required. While some scientific literature exists on scheduling of such training at the individual level on procedural tasks, the CF operates at an organizational level with an increasing high level of technology and with a growing emphasis on cognitive tasks. Hence, a scientific basis for conceptualising and predicting the retention of performance on collective tasks is required.

This issue has also been recognized by Canada's allies, and some theory development and data collection has occurred, but a well developed approach has not emerged.

## 1.1 Purpose

The ultimate goal is to field a validated model to be used by military personnel to schedule the training of collective tasks. The purpose of this project was to review published and unpublished data and theory from the military research and development community pertaining to the retention of collective and cognitive skills together with contributions from the general scientific literature.

## 1.2 Organization of the Report

The report is organized in the following sections, starting with the present one.

- Statement of Work, deliverables and approach.
- Brief background to training in military.
- Collectives and collective tasks
- Collective skill development and retention
- Factors affecting collective skill retention
- Existing models of collective skill retention
- A way ahead

## 1.3 Work Items

The following work items were conducted.

- Search and review available literature, incorporating available TTCP reports.
- Develop a categorisation framework and analyse models found in the literature.
- Develop a prediction approach for selected factors related to collective and cognitive skill retention.
- Prepare a report and make a presentation.

## 1.4 Deliverables

- Fifteen hard copies of the work prepared according to TTCP publication format.
- One copy of an MS Powerpoint presentation summarising the work.
- One copy of the work in MS Word on CD-ROM.

## 1.5 Approach

Our main focus has been on research in military domain, and on the collective skills and tasks relevant to the military context. We have assumed that the eventual system for predicting collective skill retention must be workable within the established systems of military training.

## 1.6 Method

### 1.6.1 Develop Framework

The first step of this literature review was to develop a framework for organising the search and interpreting the results. A related goal was to characterize the nature of collective training (and collective tasks) within the military domain.

Factors with potential relevance to collective and cognitive skill retention were grouped and discussed in the report as follows.

- Nature of the collective and cognitive task
- Nature of the collective
- Individual differences within the collective
- Collective training factors

The first set of factors relates to the unique features of collective tasks. Several features of collective tasks likely to impact on collective skill retention were explored, including complexity of the task, and the extent to which a task requires extensive co-ordination for successful completion. Most research in skill retention has been devoted to perceptual-motor skills, and the need for research in retention of cognitive tasks is discussed.

The second set of factors concern the nature of the collective such the size of the collective, organizational structure, and the social environment within it.

The third set of factors relates to individual differences such as aptitude and expertise evident within the collective.

The fourth set of factors considers training related issues such as training strategies, knowledge of results, characteristics of the retention interval, type and scheduling of practice in key collective tasks.

### 1.6.2 Consult TTCP members

Contact with members of the TTCP committee was limited by the time available and, in general, the responses confirmed the outcome of the literature search i.e. that there is little relevant work available.

### 1.6.3 Search Literature

Relevant databases providing access to information about collective and cognitive skill retention in the military domain, as well as in the broader scientific domain were searched including psychology, human factors, military, business and other related domains.

A comprehensive set of keywords was selected to focus and guide the search, based on experience in conducting a previous skill retention literature review and on input from TTCP committee members.

These keywords were then applied to the relevant databases and roughly 150 potentially relevant abstracts and titles were identified. These abstracts and titles were filtered in terms of their scope, level of detail, and relevance to the problem of collective skill retention. The literature that we retrieved during the search came from many different areas, including the industrial/organizational literature and the team performance literature. Although there were many articles that touched on collective skill retention, to keep within the scope of the review, a much smaller set of articles were deemed to directly address this issue. Of these articles, 20 articles were selected for detailed review and these became the basis of this report.

### 1.6.4 Review Selected Articles

Each of the twenty articles selected were reviewed with respect to:

- Factors and issues relevant to collective and cognitive skill retention
- Existing theories and models relevant to collective and cognitive skill retention
- Developing an approach to predicting collective and cognitive skill retention

### 1.6.5 Generate Survey of Literature and Lessons Learned

We evaluated the models in the articles found with respect to the scientific validity and applicability to the military TTCP domain. More specifically, our analysis:

- Reviewed existing models with respect to the categorization framework to understand their strengths and weaknesses.
- Suggested alterations to the framework, and identified the need for more data to provide direction for research and theory needed to further models of collective skill retention.
- Generated recommendations for elaborating existing theories of collective skill retention and new approaches to studying collective skill retention.

## 1.8 Acronyms

| | | | |
|---|---|---|---|
| ARI | Army Research Institute | NTIS | National Technical Information Service |
| CF | Canadian Forces | R & D | Research and Development |
| CISTI | Canadian Institute for Scientific and Technical Information | SA | Scientific Authority |
| CTEP | Collective Task Effect Prediction | SME | Subject Matter Expert |
| DCIEM | Defence and Civil Institute of Environmental Medicine | TTCP | Technical Cooperation Program |
| JRTC | Joint Readiness Training Center | UDA | User's Decision Aid |
| MOS | Military Occupational Specialty | UTEP | Unit Type Effect Prediction |

**Table 1: List of Acronyms**

# 2. Background

This project was conducted within the context of a Canadian model for military training for combat arms skills, but the general intent is for this work to be applicable to any NATO military training: army, navy or airforce.

Military training covers a wide variety of skills for both individual tasks involving different combinations of perceptual-motor and cognitive skills and team or collective tasks that require several individuals or teams, often with different skills and performing complementary tasks requiring split second interaction. Co-ordination and information exchange are important aspects of most collective tasks.

## 2.1. Military Approach to Training

Skill retention, and any refresher training to offset skill decay, needs to be set in the general context of military training. In outline, a military career progresses from training on individual skills and tasks to team (or small collective) tasks to large collective tasks. Recruit training in basic individual military skills and some basic special to arm skills will be followed by unit training as part of a team such as a vehicle crew, or infantry section. Generally speaking, collective training starts within a single purpose organization (such as an infantry company or armoured squadron). Finally, comes training as a multi-purpose group (e.g. as a combat team comprising artillery, infantry, armour, engineers, logistic units). A similar, progressive, approach to training characterizes training in other service organizations, and joint service training.

Annual unit training cycles also follow a progressive pattern, often starting after an annual period of postings and vacations (often in the summer) and specialist or trade training away from the unit. The annual cycle commonly begins with individual skills and progresses through team or sub-unit training up to formation training. Mission training may require up to six months of focussed training prior to deployment. A between year rotational cycle may also be established with one year on a mission or as part of a rapid deployment force, one year reconstituting after a mission, and one year spent in collective training and mission preparation. This general approach is illustrated below in Figure 1.[1]

[1] The relationship between "teams" and "collectives" is discussed in more detail later in the report.

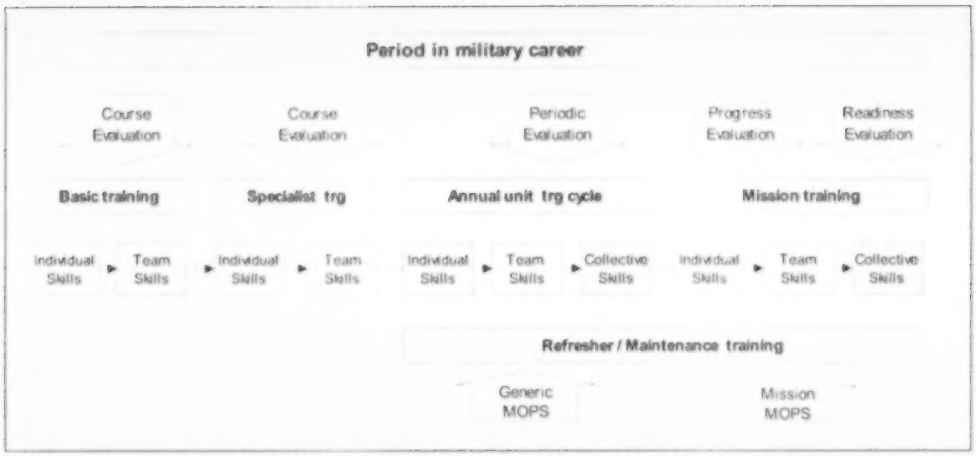


**Figure 1: General training framework** (MOP: Measure of Performance)

## 2.2. Constraints Affecting Training

The quality and amount of training will be limited by a number of budgetary and practical constraints. These constraints include equipment availability and maintenance, ammunition, accommodation and ground / air transportation, personnel and logistic costs. In peacetime it may be difficult and/or expensive to achieve appropriate levels of realism to represent the stress of battle by using live or simulated ammunition. Additional training of supplementary personnel, possibly from reserve units, may be required to bring peacetime organizations to war-time strength and capability. There is increasing use of training simulators for individual and collective skills – sometimes linking widely distributed simulators in different locations. Environmental regulations may also limit the type of training that be conducted in certain areas.

**Figure 2: Armoured Vehicle Crew Training**

## 2.3. Reference Examples

As reference points during the review and discussion of the issues of interest in this report, we have kept in mind two examples of hypothetical teams or collectives. One example is a three person tank crew comprising a gunner, driver, and a vehicle commander. This example allows consideration of basic individual skills of each of the three crew positions, as well as the interaction of these skills. Other skills related to the performance of a larger collective (i.e. several vehicle crews working together) can also be considered. Selection of a tank crew as an example also allows consideration of the effect of various permutations and combinations of organizational level.

The other example is a hypothetical operations room in a naval frigate. The operation of a frigate is controlled by an operations room team of some twenty personnel. This team receives radar, electronic, and acoustic data from various sensors, as well as visual reports, intelligence information and message traffic. This activity is directed by an operations room officer working through the directors of two warfare teams: one for above surface operations and one for below surface operations. The command team comprises the ship's captain, the operations room officer and the two warfare directors. This example permits consideration of collective issues requiring the co-ordination of diverse tasks and skills. Such teams operate at the perceptual and cognitive level for the purpose of co-ordinating subordinate levels within the ship, but also at a broader level working to co-ordinate the activity of the ship in relation to other units of a larger collective or task group.

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# 3. Collectives & Collective Skills and Tasks

Our first observation is that the term "*collective*" in relation to skills and tasks does not appear to be in general use in the scientific literature. A search using "collective" as a key word revealed only two relevant articles. Where it is used, its application seems largely irrelevant to the focus of this review. In social psychology, for instance, the term refers to the behaviour such as football crowds, riots, panic during escapes, stock market runs, and so (Brown, 1965). The term(s) of choice in the literature are team, crew, group, organization but even these are seldom used in relation to skill retention. The term "*collective*" as used to describe the focus of this review appears to be uniquely military, with no authoritative definition found. Roth (1992) for example, in the only study found on collective training as such, conducted for the U.S. Army, attempts no definitional framework. This begs the question: does the use of the term add any value over the use of existing terms, or does it just add confusion? The purpose of this section, therefore, is to discuss the nature of "collectives" and "collective" skills and tasks, in relation to other terms used in the literature.

## 3.1 Defining Collectives

The diagram below illustrates a simple hypothetical "collective" comprising three "Units", each unit comprising three "teams" or crews, and each team, three individuals. Among the group of three, there is assumed to one position that has a leadership or co-ordination role. Thus, each crew has a leader or commander, and those commanders co-ordinate between them the activities of the unit as a whole. In turn, each unit has one commander who co-ordinates with the commanders of other units to control the activities of the collective as a whole. This analysis can be pursued up through successive organizational levels ad infinitum but, at some point, a specialized command or co-ordination role may emerge. This is not represented in the diagram but, in reality, would occur and be represented by a specialized "commander" with, in larger collectives, a team of specialized "staff" to support to the command and co-ordination role.

Although three is chosen for the number of members at each level in the collective, this is solely for simplicity, and the range of numbers that actually or best occur at any level within the collective depends on the allocation of functions with respect the tasks it has to perform, and the equipment with which it is provided. Moreover, as numbers at any level of a collective grow, it seems likely that the total number will be become decomposed into sub-groups that best fit the functional goals in question, or the scope of the ability to co-ordinate. The way in which that happens remains, and how it might be idealized, remains an open question.

In the illustration, it is assumed that each "unit" can have a different function (e.g. within an army combat team an armoured squadron, infantry company and engineer troop or within a ship, departments such as operations, combat systems, or propulsion systems). To fulfil the unit function, the composite crews may be either more or less identical or more or less specialized.

Consideration of this hypothetical collective leads to the observation that collectives may operate at multiple levels, more or less simultaneously i.e. within each team, among the crew leaders with each unit, and so on. Formal or informal co-ordination may also take place among individuals with common specialities spread among different teams or units. For instance, the underwater warfare specialist teams in different ships may co-ordinate technical information laterally and operational information vertically within the command structure.

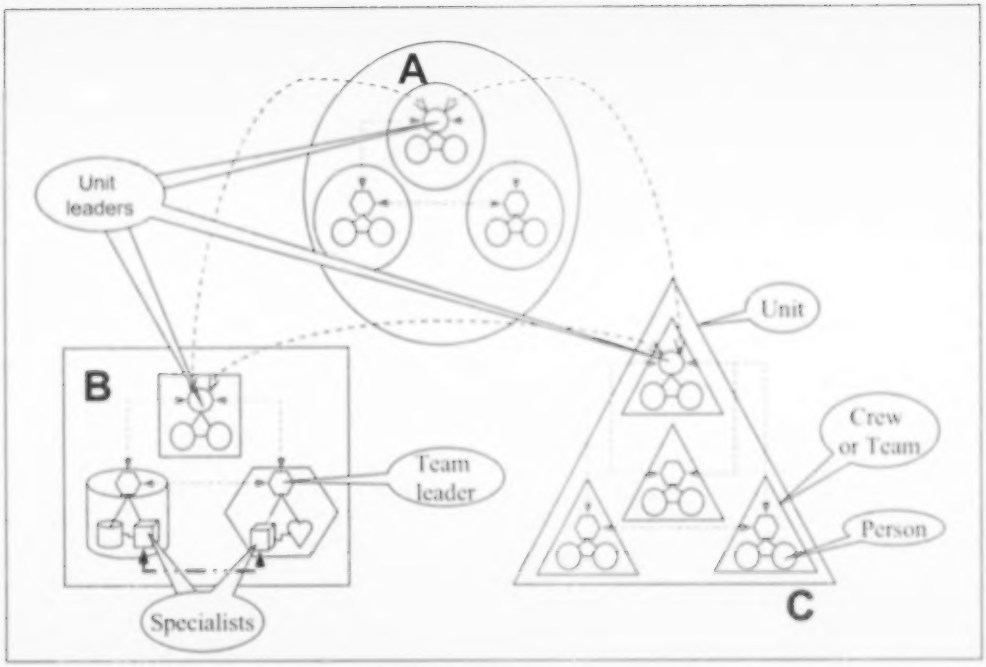


**Figure 3: Structure of a hypothetical collective**

The term "*collective*", as defined in the Canadian Dictionary of the English Language, denotes "*a number of people acting as a group*" (ITP Nelson, 1997). However, this simple definition is essentially passive and misses the rich range of potential organizational options and the degree of interdependence and co-ordination required, depending on the task(s) of the collective (see next section).

Thus, the term collective can be understood at varying levels of analysis. At the simplest level, individuals are the "building blocks". At the next level, "team" or "crew" is a commonly used term with the core features of a team often defined as two or more individuals who work together in order to achieve a specific goal (Dieterly, 1988). At a higher level yet, multiple teams can combine to form a larger collective.

Thus, it is difficult to say what distinguishes a team from a collective, or a collective from an organization. The inherent aspects of teams are that their members interact frequently to conduct mutually interdependent tasks in pursuit of a common goal. The inherent aspect of an organization seems to be that the unit of analysis shifts from the individual to the team: a team of teams. This involves a division of labour and some distribution or hierarchy of authority in pursuit of a common goal or goals (Hendrick, 1977). It is not readily apparent what the concept of a collective adds to this.

One may regard a collective (or organization or team) as any set of two or more individuals or teams that work together for the specific purpose of accomplishing a task. A team might indicate a smaller collective, and a unit or sub-unit a larger collective, but that there is really no upper limit to the size or complexity of a collective. However, this poses a practical problem in relation to measurement of skill decay. If one chooses outcome measures collective by collective, there will be virtually no limit in

measures of performance. There needs to be a measurement set for each type and level of collective. This suggests that it would be preferable, from a practical point of view, to choose process measures related to collective skills held in common across a range of collective structures and tasks.

The structure of collectives may be differentiated along a number of dimensions – size, permanence (i.e. duration of membership of a collective – as an individual or as a team), interdependence of component parts (individuals, teams or units), level of specialisation, and the co-ordination required. Less tangible but nevertheless important factors may also arise such as the trust and motivation within and between groups. Many of these dimensions have the potential to affect skill retention (or related performance).

Because research relevant to collective skill retention has focused mainly at the small team level (Turnage et al., 1990), this review has tended to concentrate on smaller, more enduring and coherent collectives. In part, also, this is because the defining characteristic of collectives appears to be the need for co-ordination and information exchange among mutually dependent different elements to achieve a specific goal. In turn, largely cognitive functions of goal setting, planning and co-ordination may themselves be conducted by specialized teams in larger collectives, and "virtual teams" comprising team leaders in smaller collectives. As our review will explore, different types of collectives may, by virtue of their structure, size etc. may be subject to unique factors that affect skill retention.

## 3.2 Defining Collective Skills and Tasks

Turning from the structure of the collective to the tasks they perform, a point of departure is the relationship between the constructs of "*task*" and "*skill*", both of which are used frequently in the literature on training, acquisition and retention.

Commonly a "*task*" refers to a piece of work to be done, and is typically depicted as a specific sequence of steps to be achieved. Since most collectives may be called on to perform more than one task, there are far more tasks than collectives. This poses a practical problem for measuring collective performance at the task level: there are very many and they are very varied.

For each collective task, there will be a number of sub-tasks that have to be performed by individuals or sub-units within the collective. Some of these sub-tasks may require information exchange among collective members.

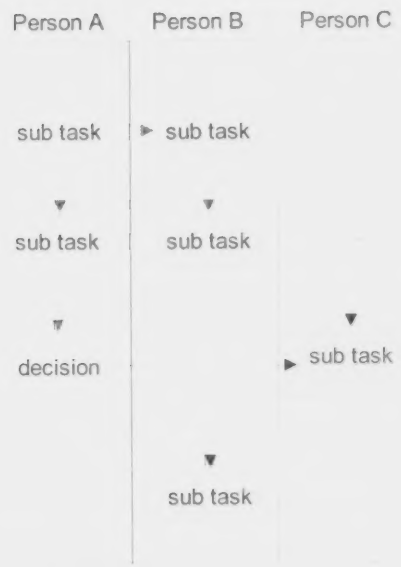


**Figure 4: A hypothetical collective task and sub-tasks**

The interdependence of these tasks in terms of speed, accuracy, and timeliness leads to the idea of sub-task "*criticality*" as important and relevant to the analysis of collective work. Some sub-tasks will need to be performed in sequence, to a certain level of accuracy, within a certain time window. If these sub-tasks are delayed or performed with sub-standard results, then the performance of the collective task as a whole will be affected to a greater or lesser degree. Other sub-tasks will be less critical. Thus "criticality" can stretch from having severe or fatal effects on collective task performance to minor or trivial effects. Retention for non-critical tasks can be expected to have less of an effect on overall collective performance. This observation suggests, in turn, that some form of team or collective task analysis would be beneficial in predicting the impact of skill retention on collective tasks. This is the view of Dieterley (1988) who also notes the absence of such an analysis method in the literature and the need to establish measures such as a sub-task interaction ratio as an index of interdependence among critical sub-tasks within overall collective tasks. Dieterley also raises the issue of function allocation within teams, pointing out that function allocation among team members will determine the interaction ratio – and that function allocation is a matter of initial system design, and its subsequent adaptation to different circumstances.

A "*skill*", on the other hand, refers to the generic underlying ability or abilities needed to perform an individual task or range of tasks (such as keyboard skills or marksmanship), or, alternatively, to the manner in which the task is performed (well or poorly). For teams and, by extension, collectives, skills can be separated into individual skills required for individual sub-tasks in the team and collective skills for tasks required for performance as unit members – such as information exchange, planning and co-ordination (Roth, 1992). Morgan et al. (1986; cited in Swezey and Llaneras, 1997) makes a further distinction between task work skills (individual ability to perform tasks) and team work skills (the group's ability to perform together). This implies measurement of skills at both the individual and the team level.

Others (e.g. Rasmussen, 1990; Vicente, 1999) separate skill, rule and knowledge based behaviours. *Skill based behaviours* are simple stimulus-response sequences that can be learned by frequent rehearsal and become highly automated. *Rule based behaviours* represents routine stimulus response action sequences that have became automatic through long practice; rule based behaviours represent conscious choices based on unambiguous procedural decision rules requiring the ability to distinguish clearly between situations. *Knowledge based behaviours* require reasoning based on some symbolic mental representation of the problem space in question, in the absence of familiar cues and clear precedents. These and other somewhat similar formulations can be related to the stages of learning (e.g. Anderson, 1982; Gagne, 1965) whereby the stage of acquisition progresses from, for example, a cognitive associative stage using declarative knowledge to develop rules to govern behaviour, and eventually reaching an autonomous stage whereby procedures become automatic. Retention of individual skills is thought by some to depend on the level of learning reached. Plateaux in performance observed during training have sometimes been thought to relate to different acquisition stages (Swezey and Llaneras, 1997). If this is so, one might speculate about the existence of plateaux in decay, possibly relating to qualitatively different stages of decay.

Within military collectives, individual sub tasks may be performed largely independently by members of the collective. Many more, however, require co-ordination among interdependent tasks performed by other team members to complete the task effectively.

However, not every component of a collective task is necessarily shared, and individual skills as well as team or collective skills can be critical in performing some collective tasks. Some of the tasks performed by collectives could be seen as several different individual tasks with very little overlap, all of which must completed before completion of the overall collective task. At issue is the extent to which performance of any given collective overall task is influenced by the completion of component team or individual sub-tasks, and therefore affected by decay in either team or individual skills. The implication is that understanding retention at the individual level is likely an important part of understanding collective retention but cannot, on its own, provide an accurate account of skill retention within collective contexts.

## 3.3 Collective Cognitive Skills and Tasks

For individual skills, some (e.g. Swezey and Llaneras, 1997; Sabol and Wisher, 2001) use the term "cognitive" to refer to the decision making phase in the sequence of performing any task performance: i.e. first knowledge retrieval (including memory for procedures), then decision making (as in fault diagnosis for equipment, and tactical planning), and finally execution (primarily psycho-motor or perceptual activities, such as tracking a target).

Recent work (e.g. Salas and Cannon-Bowers, 2001) models the cognitive aspects of team work (as opposed to individual task work) in terms of the degree to which team members shared a common understanding and knowledge of the team task, the capabilities of team members and the context in which the work is to be performed. Swezey et al. (1994) suggest that there are four re-requisites for effective team performance: information exchange, effective co-ordination, periodic adjustment to changes in task demands, and an agreed organization within the group. Matthews and Webb (1993) concluded that the three key processes to assess for command and control were effective communication or information exchange, situation awareness and decision making.

Knowledge acquisition (for instance for shared team mental models) may be thought of in terms of declarative knowledge (academic knowledge that can be readily taught) and tacit knowledge (practical knowledge acquired through experience) (Horvath et al., 1994a, 1994b). Acquisition and retention of

tacit knowledge is likely quite relevant to collective performance, and there have been extensive content studies of different aspects of tacit knowledge among effective managers and for military leadership (Horvath, 1994a, 1994b). Further work may well exist in the literature that examines acquisition and retention of tacit knowledge required for collective tasks. For example, where team membership is stable, relevant tacit knowledge for the capabilities of other team members may be acquired during the retention interval through performance on other tasks.

## 3.4 Conclusion

'*Collectives*' may be thought of largely in terms of team and organizational structures. Collective tasks can be considered in terms of individual sub-tasks, critical sub-tasks, interactive sub-tasks tasks, and team tasks, with the relative contribution each to collective performance varying with the collective task. Uniquely collective skills can be considered in terms of individual interactive skills and team work skills such as co-ordination, communication and information exchange in relation to internalized team mental models and awareness of internal team status with respect to sub-task performance, and as such can be seen as largely cognitive. This suggests that decay in cognitive sub-tasks and the cognitive aspects of collective tasks such as retention of knowledge relating to different components of team mental models should be considered within the overall framework of either individual or collective skill retention, rather than as distinct and separate issue.

# 4. Collective Skill Retention and Fading

The purpose of this section is to outline some general issues prior to a more detailed discussion in subsequent sections of factors likely to affect retention of collective performance, and existing models for predicting retention.

Skill fading can be described as the measurable decrement in performance of a skill in relation to a criterion. Skill retention has been defined as the maintenance of skills as learned behaviors and procedures over long periods of time without practice (Schendel & Hagman, 1991). Skills fading is thought to occur because perceptual, motor, or cognitive processes that underlie skilled performance decay or break down in some way. This may be because a subordinate execution skill has decayed (such as keyboarding), or memory for mental model for the rules or knowledge governing the exercise of that component skill has faded or become inappropriate. Alternatively, the skill may remain intact but become inaccessible to the individual in some way. Thus, performance on some sub-task may or may not reflect actual decay in the underlying knowledge or skill: this represents a considerable methodological challenge to control, for instance, the effect of motivation on a team or individual during a retention test and to interpret the results of retention data based on performance data.

Individual skill retention is often described using a power function, which relates performance to the interval between initial training and subsequent testing (Shute and Gawlick, 1995). This function is typically seen as negatively accelerated, with performance declining most rapidly soon after learning, but at lesser rates over time. Indeed, most learning functions (acquisition, transfer of training) appear best described by a power function (Newell and Robinson (1981; cited in Swezey and Llaneras (1997).

Skill loss can be characterized with two parameters. The slope of the curve describes the rate at which skill is lost. The asymptote describes the level at which performance levels out. The power function offers the most accurate description of retention for a range of tasks and materials (Bryant and Angel, 2000), with different skills showing different rates of decay, and some military skills exhibiting a severe performance decrement in as little as two weeks. Generally memory for knowledge exhibits the most rapid decay and continuous perceptual motor skills the slowest rate (Wisher et al., 1991).

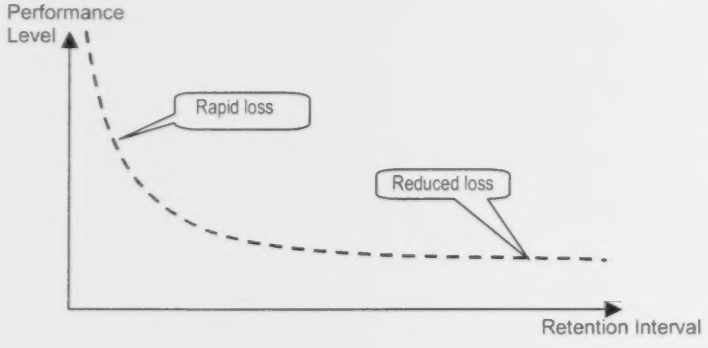


**Figure 5: A typical retention curve.**

## 4.1 Skill Development

Anderson (1995), describes skill acquisition as occurring in 3 sequential stages.

- *Cognitive.* An individual first develops knowledge of the task in the form of rules, procedures and constraints called *declarative knowledge*. Accessing this knowledge requires conscious recall effort, and, if retrieved successfully, this knowledge can be used to guide performance.
- *Associative.* With practice and knowledge of results, the individual becomes increasingly adept in associating cues with task steps. These associations form an increasingly elaborated system of if-then rules that guide behaviour.
- *Autonomous.* Associations that have formed become increasingly automatic, and can be retrieved and executed with little conscious effort. Performance may be thought of as a procedural response to situational cues.

Over these stages, individuals acquire expertise or mental models of domain knowledge in terms of content (concepts, cues, procedures, etc) and organization for retrieval during the task. This theory of skill development describes the process that an individual undergoes during skill acquisition. The question is whether collective or team or team performance can be considered in terms of individual skills jointly exercised or must be conceptualized in a different way. The former view assumes that individual team members can acquire skills such as co-ordination and information exchange, and lends itself to study of individual skill retention curves for interactive skills and team related knowledge in order to predict retention of collective performance.

Although we were not able to identify any models of collective skill acquisition as such, one model of skill acquisition for teams is the Team Evolution and Maturation (TEAM) Research Paradigm. This model proposes that, as teams mature, there are two different but parallel "tracks" of skill development (Morgan et al., 1986; cited in Swezey and Llaneras, 1997): task work and teamwork (see Figure 6).

- *Task work* skills refer to an individual's ability to perform their role in the team.
- *Teamwork* skills refer to the group's ability to perform together in terms of information exchange, overall awareness, and adaptation.

Taken together with Roth's (1992) somewhat different distinction between individual skills and collective skills, this suggests there may be three types of skill to be distinguished. *Individual skills* for the one person tasks in the team (can be trained as an individual). *Interactive skills* required by the individual to perform as a team member (can be partly trained as an individual in isolation from any team task). *Team skills* used only in the context of a particular team and a particular task (cannot be learned in isolation from other members of the team).

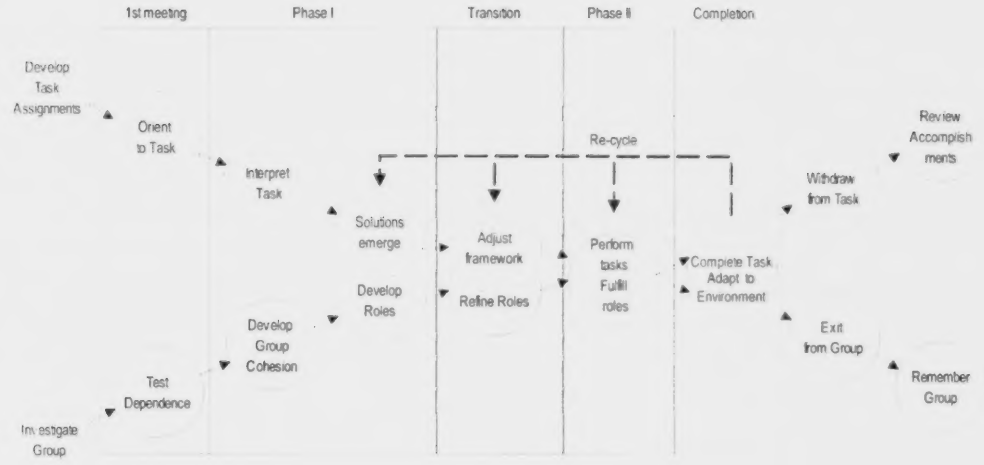


**Figure 6: Team evolution model Adapted from the TEAM model (Morgan et al 1986)**

The TEAM model applies to skill development not skill retention but it seems likely that retention of collective performance will depend on the stage of team evolution reached when measurement of retention starts. There is also the issue of what to measure and the need to develop effective measures for interactive skills and team skills in addition to individual skills. One implication of the model is that team evolution is related not only to team membership but to particular tasks. This raises the question of transfer of team work skills from one task to another, with the answer likely dependent on the degree of similarity between the two tasks, combined in some way with the level of maturation of the team with respect to other tasks.

## 4.2 Retention of Individual Skills

Considerable work has examined how different performance on individual tasks is maintained over time. A recent review by Sabol and Wisher (2001), for example, considers the current state of skill decay research with respect to individual military tasks and distinguishes between knowledge, decision and execution skills present to differing degrees in all tasks.

- *Knowledge-based skills* fade substantially in the first few months after training, but the degree of fading depends on how that knowledge is measured, and whether the test demands recognition or recall (Wisher et al., 1999). Within knowledge based tasks, memory for complex procedural tasks is likely to decay more quickly (Schendel and Hagman, 1991; Sabol and Wisher, 2001).
- *Cognitive or decision-based skills including problem solving* show moderate rates of decay. Work by Semb and Ellis (1994; reported in Sabol and Wisher, 2001) summarising more than 20 studies with both military and non-military tasks, suggests that these decay in the region of 20% over periods of 3-6 months or longer.

- *Execution skills or perceptual-motor skills* vary in their decay. Rates of decay depend greatly on whether the skill is continuous (having no clear beginning or end, such as driving) or discrete (having a distinct start and end point, such as assembling a machine i.e. procedural tasks). Skills that are continuous have shown extremely low levels of decay even after two years without practice (Childs and Spears, 1986). Discrete or procedural skills often show marked decay in a few weeks.

However, the time span over which retention has been studied is typically short. Moreover, rates of decay vary widely, and the type of tasks studied and the manner of measurement in acquisition and retention studies often are unrepresentative of real world tasks, or use subjects with limited experience of the task in question (Swezey and Llaneras, 1997).

Bryant and Angel (2000) focused on individual skill retention and focused on models of skill fading/retention and tools for determining when refresher training is required in the military and examined eight factors shown to affect skill retention:

- Retention Interval.
- Opportunity to practice.
- Degree of initial learning or over-learning.
- Method of training.
- Similarity of training and performance environments.
- Type of task
- Method of testing.
- Individual differences.

Several classes of models for predicting skill retention were identified.

- *Subjective approaches* involve some form of self-assessment of retention and/or the need for refresher training on the part of trained individuals. These techniques may yield accurate estimates of retention but tend to be consistently optimistic and tend to be mistrusted as a predictive tool.
- *Qualitative approaches* indicate categorically how skills fade over time in relation to certain key factors. These models, as they stand to date, are more proscriptive than predictive (offering strategies to reduce skill loss rather than means to predict rate of skill loss) and do not solve the practical problems of predicting when proficiency of skills will decline below a criterion or when refresher training will be needed but they do offer approaches that may be developed into quantitative models in the future.
- *Quantitative approaches* - The best developed model of skill retention found by Bryant and Angel (2000) was the U.S. Army Research Institute's Users' Decision Aid (UDA) model, developed specifically to provide quantitative predictions of skill retention for military tasks. The UDA model is more applicable to the prediction of procedural and perceptual-motor abilities than cognitive abilities and is described in some detail in a following section.

## 4.3 Conceptualising Collective Skill Retention

Collectives or teams and their tasks can vary in several ways that may interact with skill retention.

- The interdependence of organizational structure (e.g. the division of specialty skills among collective members and sub-groups).
- The number of levels within the organization.
- Interdependence of tasks performed by team members or sub-groups to complete the collective task in question. This interdependence may be in terms of the need to exchange information, or in terms of the criticality of sub-tasks with respect to speed, accuracy or timeliness of performance.
- The balance of individual, interactive, and teamwork skills required for the task.
- The balance between knowledge, decision and execution skills required for the task.
- The period of time over which the team or collective has worked together
- The types of events experienced during the retention interval and their relevance to the collective task of interest.
- The degree of evolution as a team for the task in question.
- The degree of membership change over the retention interval.

Some collective tasks depend primarily on sub-tasks requiring little interaction or co-ordination between collective members. (For example a group of phone operators.) In such cases, the overall performance of the collective is primarily an aggregate of individual performance. (More phone operators result in more phone calls handled.) Other collective tasks rely heavily on co-ordinated sub-tasks among several people. In turn, the tasks to be co-ordinated may be virtually identical (a team of rowers) or differentiated (a tank crew). In each case the balance of skill types will vary. As such, the "collectivity" of any task will vary along the dimension of how much interaction and/or co-ordination is required to complete the task.

Consideration of the issues outlined above leads to the following observations.

- For tasks where collective members perform primarily as individuals, with less need for interdependence or interaction among sub-tasks, decay can be conceptualized as some aggregate of the rate for individual sub-task skills. With little co-ordination required, the rate of decay in the overall task of the collective will relate most closely performance on individual tasks, not their co-ordination.

  Thus, for tasks in which collective members function as relatively independent agents, the best predictor of collective skill retention may be the retention curves for individual sub-tasks, which in turn will depend on the type of sub-task involved: knowledge based, decision based, perceptual motor. Prediction might need to be modified by the degree to which resources can be re-allocated within the collective to compensate for differences in rates of decay among individual collective members.

- The greater the interaction required among interdependent and critical collective sub-tasks, the more retention of performance will depend on the rate of decay of individual interactive skills and group team work skills, in addition to the rate of decay of individual task work skills.

- The more specialized the skills among individuals (or sub-units) in the collective, the greater will be the interdependence of the critical sub-tasks they perform. Thus, as the level of specialization rises, the greater will be the dependence of the overall collective

task on decay of specialized task work skills. Conversely, the more it can be generalized the skills among collective members (perhaps as a result of more cross training, or for a system with sub-tasks based on more generic transportable skills), the less dependent will overall collective performance be on critical sub-tasks.

- With a rise in the number horizontal and vertical subdivisions in the organization (e.g. the more teams it contains), dependence on team work skills will increase, especially with respect to information exchange and awareness among team members of progress on critical tasks (and among team leaders, progress of other teams).

## 4.4 Retention of Collective Skills

Most of the foregoing observations are based on extrapolation for little research was found that directly addresses the issue of how long performance on collective or team tasks is likely to be retained. Roth (1992) notes that although a considerable amount is known about the effects of time without training on individual task performance, *"Essentially no previous work on skill decay in collective tasks has been done for real-world tasks."* Even work directly intended to explore tank gunnery skills, for example, concluded with regret that, in the end, there is little if any research which focuses on the collective rather than the individual level (Rowatt and Shlechter, 1992).

The only available work on collective skill retention suggests that collective task proficiency is negatively affected by a retention interval of less than one month (Roth, 1992). To assess this, Roth compared performance scores over a period of one month for several Light Infantry platoons on fourteen collective tasks, such as employing fire support, occupying a patrol base, performing aerial re-supply and moving tactically. The original measures were collected after training conducted by the platoon's parent division and represented the number of sub-tasks rated as acceptable according to training evaluation standards. The second measure, collected one month later, was done during training at the Joint Readiness Training Centre (JRTC), using the same measures, apparently completed, in both cases, by the unit commanders.

| Task Title | Number of Platoons Scored on the Task | External Evaluation Performance Score | JRTC Performance Score | Performance Change in One Month |
|---|---|---|---|---|
| 1. Infiltrate/Ex-filtrate | 5 | .53 | .93 | +.40 |
| 2. Perform Aerial Re-supply | 2 | .57 | .59 | +.02 |
| 3. Sustain | 4 | .75 | .81 | +.06 |
| 4. Perform a Passage of Lines | 1 | 1.00 | 1.00 | 0 |
| 5. Move Tactically | 9 | .67 | .63 | -.04 |
| 6. Occupy a Patrol Base | 1 | .88 | .75 | -.06 |
| 7. Consolidate and Reorganize | 6 | .67 | .50 | -.17 |
| 8. Occupy an Assembly Area | 7 | .84 | .67 | -.17 |
| 9. Employ Fire Support | 4 | .90 | .68 | -.21 |
| 10. Perform Helicopter Movement | 1 | .96 | .63 | -.23 |
| 11. Perform Link-Up | 3 | .83 | .58 | -.25 |
| 12. Assault | 1 | .75 | .50 | -.25 |
| 13. Occupy OP/Perform Surveillance | 2 | .88 | .60 | -.28 |
| 14. Perform Tactical Road March | 1 | .92 | .57 | -.34 |
| **Means** | **-** | **.78** | **.67** | **-.11** |

**Table 2: Collective task performance scores over a one-month interval (Roth, 1992)**

As the table shows, while some of the collective tasks deteriorated over the month, with the average decrement of about 11%, six out of fourteen improved or showed little change. Of those that did decay, the average performance decrement was closer to 25%. There was no analysis of the collective tasks in terms of their need for interaction or the interdependence of the sub-tasks. The variety of tasks performed, the wide fluctuations in the sample sizes for different tasks and the fact that the evaluation was conducted by the unit commanders call into question the reliability of the data. Nevertheless, as Roth notes, the average performance deterioration is similar to the rates evidenced for individual tasks shown to be fairly resistant to skill decay (Rose et al., 1995a).

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# 5. Predicting Collective Skill Retention

The purpose of this section is to explore factors that may affect retention of performance on collective tasks. We found little research and theory that discusses the prediction and retention of collective performance as such. This likelihood was recognized from the start and, consequently, much of this discussion is speculation based largely on extrapolation from the literature on individual skill retention and team work, and intended to foster debate and serve as a point of departure. [2]

Performance of collective tasks depends, in differing degrees for different collective tasks, on individual skills for sub-tasks on the critical path for collective performance and on individual interactive skills. Retention for such skills is likely to follow a similar pattern as individual skill retention. In general, we believe that many of the same factors are likely to influence skill retention at a collective level to the degree that similar tasks are present, and on the critical path for the overall collective task.

For retention at a collective level, however, the overall unit of analysis is no longer the individual, but the whole group or organization. While it is important to consider the impact of factors already implicated in individual skill retention at the collective level, we have also considered features of the collective unit likely to impact on collective skill retention.

Training at the collective level appears unique in that, especially for larger collectives, it may have no distinct start and end point from which to measure skill decay for the collective as a whole. How, for example, does one establish a retention curve for collective tasks performed at the level of a battle group based on a battalion, or even a combat team based on an infantry company. Instances of training for larger collectives may be spaced apart by as much as a year in the annual training cycle. The circumstances of that training may vary widely in terms of current team membership, the level of evolution of the team(s) in the collective, the exact nature of the collective task, and the circumstances in which it is undertaken. Test re-test data may have to be collected under very different circumstances, making measurement of decay under controlled comparable conditions difficult or even impossible. On the other hand, individual skills for independent sub-tasks and, to a lesser extent, interactive skills possessed at the individual level, may be trained and assessed at the individual level – making study more practicable.

*(In the search for practical methodologies and suitable collective tasks and teams to study, there may be merit in examining team training simulators used in different services. Such an example might be the Operations Room Team Trainer recently brought into service for the HALIFAX class frigate. This trainer is capable of conducting watch and watch about team training simultaneously for two established ship's operation room teams (approximately 30 persons) over prolonged periods. It also provides sophisticated data capture and archiving capabilities that would permit comparison of team performance across different intervals and conditions. Once common dimensions likely of fundamental interest to collective performance have been identified, such fundamentals could be examined across service boundaries.)*

This section discusses the sets of factors in the following order:

- Features of the collective task

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[2] A previous literature review examined factors known to influence individual skill retention (Bryant and Angel, 2000) and the reader is referred to that work.

- Features of the collective itself
- Characteristics of individuals forming the collective
- Features of the training received by the collective
- Characteristics of the retention interval.

## 5.1 Features of the Collective Task

The literature on individual skill retention suggests several task features likely to influence skill retention. These include, for example, the number of steps in the task, whether the steps of the task must be performed in a set sequence, and the existence of memory aids to perform the task (Bryant and Angel, 2000). Many such task features are present, to some degree, in collective tasks and performance is likely to be retained in much the same way.

The section covers the following features of the collective task:

- The number of collective tasks assigned to the collective unit.
- The number of steps in individual sub-tasks,
- The availability of interstep cueing within sub-tasks;
- The predictability of sub-task procedures and conditions of performance;
- The number of discrete skills required by the collective task;
- The number of sub-units needed to perform the collective task;
- Interchangeability among sub-tasks;
- Interdependence among sub-tasks;
- The potential for error compensation;
- The need for information exchange among collective members;
- The cognitive complexity of sub-tasks.

### 5.1.1 Number of collective tasks performed by the collective

Some collectives focus on only one collective task in one setting. Many military collectives may be required to perform many different tasks under a wide variety of conditions. The variety and differences among the collective tasks a given collective, such as a platoon, or ship, may be required to perform will affect the amount of knowledge and number of procedures and skills the members of the collective have to learn and retain.

Depending on the overlap between them, each different collective task may require a different skill set. This will increase the procedural and other knowledge required. There may also be longer gaps between opportunities to practice given tasks, and therefore longer retention intervals. For such reasons, Roth (1992) argues that collectives that perform more tasks are likely to show higher levels of absolute skill loss than collectives that perform fewer tasks. However, there is another way to look at this: in terms of transfer of training among the different collective tasks. Transfer of training may be positive or negative depending on the degree of similarity or commonality among the sub-tasks required and the circumstances under which they must be performed. For instance, a collective member may be required to drive for all collective tasks, or to drive for one collective task and perform some other sub-task in another collective task.

The degree of similarity between these collective tasks and their component sub-tasks will affect the transfer of training as result of practice on different tasks during the retention interval. If the other collective tasks or their sub-tasks are similar then the transfer of training will improve retention of the collective task of interest. Depending on the degree of dissimilarity, a negative transfer effect can be expected, and retention reduced.

As the number of dissimilar collective tasks assigned to the unit increases, the probability that its structure must be re-arranged for each task increases. This will add to the amount of information and differences in procedures that collective members individually and as a whole, must master and remember.

This sort of analysis may need to be repeated for the sub-tasks undertaken within each collective task.

Predictions for retention of collective performance:

- The effect on retention of the number of collective tasks assigned to a unit will depend on the degree of transfer between sub-tasks.

### 5.1.2 The number of steps in individual sub-tasks

Disregarding the need for interaction with others, for individual sub-tasks, the higher the number of steps in the task, the more complex the procedure and the greater the load on memory, and the less likely task performance is to be retained (e.g. Rose et al., 1985a).

This may affect collective performance in two ways. First, as the number of sub-tasks to be completed by the collective or team increases, the faster overall collective performance is likely to decay. Second, the greater the number of steps required by individual sub-tasks on the critical path for overall collective performance, the greater the likely effect of the faster decay of those sub-tasks on the collective task as a whole.

This factor is likely to interact with the size and diversity of specialities within the collective. Large and more diversified collectives are likely to require more co-ordination. Some aspects of co-ordination may be assigned explicitly to one or more members of the collective as a specialized command and control function. In other cases, co-ordination functions may be left to individual collective members to dovetail with their own tasks, adding steps (and possibly requiring multi-tasking) to their existing tasks, thereby increasing the complexity of the procedures and the load on memory, and with that, the rate of decay.

Predictions for collective skill retention:

- The greater the number of steps in a sub-task, the faster the rate of decay.
- The more critical the sub-task, the greater the effect on collective performance.

### 5.1.3 Availability of interstep cueing for sub-tasks

Individual sub tasks differ in the degree to which they provide feedback on performance of the past step and cueing as to the next step[3]. The training literature shows that in highly complex, or very procedural and/or lengthy tasks, interstep cueing can help individuals to first learn and then retain knowledge and execute tasks promptly and accurately (Rose et al., 1985a). For example, during

[3] Feedback in this context is a specific product of the task, and stands in contrast to feedback received during training which is discussed in the section on training.

mechanized mine breaching operation, the step by step lane clearance task is a highly choreographed procedure.

However, the benefits of feedback and cueing may diminish as individuals progress in status from novice to expert. The experienced performer may actually find that some aspects of feedback and cueing may interfere with task performance, and are better discarded or reduced. Conversely, selective and temporary re-introduction of feedback and cueing after a period away from the task may assist recollection.

Within collectives, interstep cueing is potentially even more important to the prediction of skill retention. With different people working on different aspects of the overall collective task, feedback about the correctness of past steps and prompts for future steps are likely to help all members of the collective co-ordinate among their sub-tasks and, especially collective members responsible for co-ordinating others, to gauge how well the overall collective task is progressing. The greatest benefit is likely for sub-tasks on the critical path for the collective task in question.

Predictions for retention of collective performance:

- Interstep cueing for critical and interdependent tasks will improve retention.

### 5.1.4 The predictability of sub-task procedures and context

For individual skill retention more procedural tasks are more resistant to skills fading (Sabol and Wisher, 2001). This may be because highly procedural tasks are more likely to provide consistent cues to their sequence of completion. This effect may relate partly to the similarity of the context in which the task is performed – cues may be more difficult to recognize in widely differing circumstances. (This effect probably acts in much the same way that positive transfer of training is greater under more equivalent conditions.)

Tasks that are less procedural or that cannot be made procedural require a more complex set of rules to guide performance: rules that are more likely to be forgotten. In collective work, for less procedural sub-tasks, it may also be more difficult to recognize when one sub- task is completed satisfactorily and the next, dependent, sub-task may start. This would make co-ordination more challenging.

Predictions for collective skill retention:

- Consistent and comprehensive procedures will improve retention.
- Consistent circumstances for performance will improve retention.

### 5.1.5 The number of discrete skills required for the collective task

As the number of discrete skills needed to complete a collective task increases, there will be an increase in the amount of information to be learned about how each individual sub-task intersects with others – and in the amount and quality of information that must be exchanged and comprehended across specialist boundaries (individual or team) within the collective. This increase requirement for knowledge and memory is likely to make retention of the collective task as a whole more difficult.

The higher the level of the collective within an organization (e.g. the command team for an battle group versus the command team for a infantry platoon), the more likely there is to be diversity of skills required, and more specialized the skills. As the diversity and level of specialisation among diverse skills increases in a group, then it is likely that co-ordination and co-operation will be more difficult to achieve, and collective performance will be faster to decay.

Predictions for retention of collective performance:

- As diversity of among specialists (sub-groups or individuals) increases within a collective, rates of decay will increase.
- The higher the level of the collective in the organization, the greater the diversity and level of specialisation required, and the faster the decay.

### 5.1.6 The number of sub-units needed for the collective task

Collectives tasks vary in the number of sub-units or teams involved and the number of levels at which the sub-units are organized. Commonly, for example, several different tank crews must work together rather than as individual units, organized at several levels (e.g. tank crew, troop, squadron, regiment). With more sub-units, more co-ordination will be required and more relationships among sub-units will need to be considered and understood. This will require substantial changes in how sub-units perform. Rather than working as individual units, for example, teams must now work to ensure that information is exchanged with other sub-units. This issue is discussed in more detail in section 6.1.10.

Predictions for collective skill retention:

- More sub-units will increase the rate of decay.
- More organizational levels will increase the rate of decay.

### 5.1.7 Interchangeability among sub-tasks

Sub-tasks assigned to individuals vary in the extent to which they can be performed by different members of a collective. The skills, knowledge or procedures required to perform a given sub-task may be specialized or possessed by only a few members or one team within the collective.

The extent to which a collective sub-task can be completed by several members of the team or collective is likely to improve the collective's ability to maintain overall collective performance for several reasons. If one member is unable to perform the task, other team members may be able to take over the task, or assist the individual responsible. For example, although artillery Forward Observation Officers are specially trained to call for and adjust artillery fire, other members of a combat team can also do this if needed. The degree to which collective members are cross trained in others sub-tasks and/or the level of similarity between tasks will affect this capability.

Part of this capability requires a shared mental model of the tasks of others (Mathieu et al., 2000). Insight into the sub-tasks of others is not only likely to facilitate dovetailing among interdependent individual sub-tasks but, by distributing memory for common sub-task knowledge and procedures among different collective members, overall retention within the collective as a whole is likely to improve with the possibility that one collective member can prompt others when they forget, or even substitute for them entirely. Having a shared mental model of collective sub-tasks can be expected improve the ability of the collective as a whole to complete the task and improve collective skill retention.

A related point is that, regardless of the potential for interchanging team members among sub-tasks, actually using that potential will depend on awareness of the progress and needs of others in the collective, and co-ordination of any interchanges.

Predictions for collective skill retention:

- A greater proportion of interchangeable sub-tasks will increase retention.

- Better awareness among collective members of progress among interchangeable sub-tasks will improve retention.

### 5.1.8 Interdependence among sub-tasks

The extent to which the success of collective tasks require co-ordination among team members to complete their sub-tasks, or for completed sub-tasks to be dovetailed in some way, has been cited as a crucial factor for overall success or failure of collective tasks (Dieterley, 1988; Swezey and Llaneras, 1997). Decay in performance of interdependent tasks is likely to have a marked effect on how well overall performance of the collective task is retained. Greater interdependence among sub-tasks is likely to be associated with faster decay in the overall collective task.

Interdependence has a number of dimensions. It may be, for example, that the performance of a collective task is wholly dependent on several members of the team to make a partial contribution toward the completion of the task. For a tank crew, for example, successful engagement depends on the tactics of the commander; on the loader loading the proper ammunition, on the gunner sighting the target, and on the driver manoeuvring appropriately. If part of any component task is not completed, the performance of the collective task as a whole may fail. In this example, the type of dependence combines linear and parallel dependencies, as most sub-tasks can only be completed after the previous sub-task has been completed, but some can completed in parallel.

For less interdependent collective tasks, each member of the collective may need to complete his own sub-task for the task of the collective as a whole to be completed, but an individual's ability to complete his own task may not be dependent on another person having completed their sub-task. An example might be the preparation of a defensive position – where individual fire positions all have to be completed, but the completion of one fire position may not depend on the completion of any other.

Criticality of the interdependent sub-tasks may also vary. Some sub-tasks may require continual split second timing and co-ordination – others may be less time sensitive. Criticality may also vary with respect to the quality of completion of different sub-tasks.

A task may also be performed in serial or in parallel, in relation to the structure of the team or organization. Paris, Salas, and Cannon-Bowers (2000) focus on the dependency between tasks and the people performing the tasks, and tasks are seen as being performed *independently, sequentially,* or *in parallel*. When task/operator dependency is very high, inadequate performance by one person can greatly influence the ability of another person at a different station to complete their task. Teams in which task performance is organized serially may be compromised, because team performance will be determined by the strength of the weakest link in the serial chain. Analysing and studying such complexities would require a detailed team task analysis, and comparisons among many different aspects of interdependency within collective structure and collective tasks would probably be facilitated by the use of software modelling programs such as Micro-Saint.

The number of dependencies among sub-tasks and the need for interaction related for their completion will vary for different collective tasks and different function allocations within collective structures. Furthermore, each dependency has a differing potential to disrupt the ability of the collective to perform the task. Recognizing this, Dieterly (1988) proposes calculation of separate "*Interdependence*" and "*Interaction*" ratios for team tasks based on a collective or team task analysis. An *interaction ratio* would identify the proportion among of all tasks necessary for goal achievement (i.e. on the critical path) assigned to individuals and dependent on the completion of other tasks by other individuals. An *interdependence* ratio would calculate the total number of tasks in relation to the maximum number of

sub- tasks that could be handled by one team member, in parallel or sequentially within a given period of time for completion of the overall collective task.

However, while such ratios may go some way to deal with the frequency of interaction or the number of dependencies among sub-tasks, qualitative aspects of those interactions or dependencies would remain to be addressed. Furthermore, the level of effort required to calculate such ratios is likely to be high, even for quite small collectives performing quite simple tasks. The most efficient way in which to generate such indices is probably to conduct this analysis as part of system design. Indeed, Dieterly advocates such an approach as part of the process of optimizing function allocation within teams maximize team performance and, subsequently, facilitate team training.

Dealing specifically with collectives Roth (1992) defines performance of collective tasks as being either *co-active* or *interactive*. *Co-active tasks* are those in which several collective members perform the same or similar tasks under relatively centralized direction. *Interactive tasks* require different collective members to co-ordinate substantively different tasks with other members of the collective. Roth argues that *interactive* collective tasks require more effort to learn co-ordination and division of responsibilities, and so are less likely to be retained than co-active tasks.

Predictions for collective skill retention:

- Faster decay with higher levels of sub-task interaction or interdependence.

### 5.1.9 Potential for correcting errors and re-deploying resources

The ability of teams to self-correct has been cited as a critical component for better team performance (e.g. McIntyre and Salas, 1995). Thus the potential within collectives to detect and compensate for errors is likely to have a positive influence on retention of collective performance. There are two aspects to this: the ability of individuals in the collective to detect and self-correct, and the ability of the collective to monitor resource use and re-deploy teams or individuals as required. This capability is likely to relate not only to feedback and cueing (discussed above) at an individual level but also to the structure of the collective, information exchange, and the interchangeability of sub-tasks and skills within the collective.

Collective tasks vary in the extent to which they allow for correction and/or compensating if errors occur during task performance. Some kinds of collective tasks are performed with sub-units working fairly independently on different sub-tasks. For example, sub-units preparing a defensive position, or multiple but similar equipment items (e.g. vehicles) for a mission, may complete their tasks at different times, and be re-deployed to assist sub-units falling behind. This assumes that one sub-unit will know that another needs assistance, has the knowledge and skills to provide it, and is directed to do so.

Some collective tasks may allow little room for correction if one unit falls behind or fails to perform their part, even if feedback is available that this is happening. This is more likely to occur when the tasks require specialized skill and knowledge or one sub-unit in the collective is not accessible. For example, some sub-tasks performed by tank crew members are not amenable to correction, even though other members of the crew are aware of that the sub-task is falling behind, or below standard. Other crew members may not have the knowledge or skills required. The position may not be accessible from another part of the tank. The crew member may not have any spare capacity.

Thus, where errors or delays resulting from decay in the skills of an individual member or sub-unit in the collective can be detected and compensated, and retention of overall collective performance may be improved.

Predictions for collective skill retention:

- The ability to detect and correct errors among collective members will improve collective skill retention.

### 5.1.10 The need for information exchange among collective members

Communication and information exchange will place extra demands on collective members during a collective task. Information exchange may be needed for co-ordination or as part of the task itself. The amount and qualities of the information, and the paths of communication among members of the collective will affect the nature of the communication sub-tasks, and the susceptibility to decay of the individual tasks as well as the effect on the overall task. For instance, communication among many collective members are likely to result in more complex decisions and procedures with higher error rates than communication that occurs among only a few collective members.

This factor will interact with the structure of the collective. Multiple information exchange trajectories among several sub-units organized in several levels imply a greater need for effective anticipation of the information needs of other collective members in terms of timeliness and accuracy. Information may need to be condensed or summarized as it transits through the collective. This implies a greater need for understanding of the goals and tasks of other collective members, and for awareness in terms of feedback and/or cues as to the status of other collective members tasks. The more complex the information exchange requirements of different sub-tasks, the less retention that can be expected of individual sub-tasks, and the greater the impact on overall retention of the collective task.

With more organizational levels, relational constraints and information exchange will become more complex and the quality of information exchange is more prone to error as information is filtered or compressed as it moves between levels. With an increase in either the number of vertical or horizontal levels, the negative effect of poor information exchange will increase, accelerating the impact of decay in interactive skills.

Predictions for retention of collective performance:

- Collective tasks with more complex information exchange needs in terms of information quality, quantity and number of people involved in the communication will be less likely to be retained over time.

### 5.1.11 Cognitive complexity of collective sub-tasks.

Examples of collectives with high cognitive demands include a warship's operations room of twenty to thirty people dealing with multiple and simultaneous threats in the air, on the surface and underwater and the command team of an army combat team co-ordinating the activities of its different units. Among these teams, the cognitive demands of different sub-tasks will not be equal, and will depend on the complexity of the overall collective task.

The limited research available suggests that individual cognitive or decision-based skills such as problem solving decay in the region of 20% over periods of 3-6 months (Sabol and Wisher, 2001) with memory for more complex procedures decaying faster than less complex.

As the proportion of individual, interactive or teamwork sub-tasks with high cognitive or information processing demands increases within the collective, the more closely retention of the overall task is likely to be linked to cognitive factors. Examples of cognitive tasks include knowledge retrieval, recall of procedures, and decision making task that use attention, memory and information processing resources,

and the need to multi-task using different styles of decision making. Considerations include the degree of planning required as part of the collective task, styles of decision making (for example, recognition primed or analytical), the degree to which decision making is or can be made procedural, and decision support is available.

Predictions for retention of collective performance:

- Less retention as the proportion of individual, interactive, or team work tasks requires recall of complex procedures, or impose higher cognitive demands in terms of attention, memory, decision making or multi-tasking.

### 5.1.12 Summary of Collective Task Factors

Several features of collective tasks are likely to affect the rate at which performance on collective tasks will decay over time. The number of steps in the sub-tasks, the number of distinct specialized skills required, interdependence among critical sub-tasks, the co-ordination required, and the amount, the quality and pattern of information exchange and cognitive demands are all likely to affect retention of performance on collective tasks.

A theme that emerges that distinguishes team or collective tasks from individual tasks: co-ordination. Retention is likely to be markedly affected by the degree co-ordination required among critical collective sub-tasks and, as well, the need for co-ordination will complicate sub-tasks that, otherwise, could be treated as individual tasks. The structure of collectives and collective tasks may changed by positions and sub-tasks added specifically for the purpose of co-ordination. Such function re-allocation is likely to occur when the sub-tasks assigned to one position within the collective exceed the capacity of one person to perform them acceptably.

A challenge to predicting retention is the interactive effect among task factors and other aspects of a collective. The impact of collective task factors is likely to vary depending on features of the collective itself such as its structure and the size of the collective sub-units at different organizational levels in the collective. This issue is addressed in the next section.

## 5.2 Features of the Collective

Within training research and theory, there has been increasing awareness of the need to analyse and understand system-wide influences on training within organizations (Salas and Cannon-Bowers, 2001). At the level of small team training, there has been consideration of organizational factors that impact on team skill acquisition, and on team performance (Cannon-Bowers et al., 1995). The purpose of this section is incorporate these same sort of considerations into understanding collective skill retention.

The section covers the following features of the collective:

- Structure of the collective in terms of sub-units and levels of organization
- The number of people in the collective
- Leadership structure
- The potential for role substitution
- Shared mental models of team members and team tasks.
- External turnover and internal turbulence in the collective.
- The social environment in the collective.

### 5.2.1 Structure of the collective

While consideration of organizational psychology was deemed beyond the scope of this review, some aspects can be considered, and consideration in greater depth, should undoubtedly be part of future research into the issues under consideration.

Hendrick (1997) offers following definition of an organization: "*The planned co-ordination of two or more people who, functioning on a relatively continuous basis and through division of labour and a hierarchy of authority, seek to achieve a common goal*". Overlap between this definition with the concept of a team and of a collective are plain. Related topics such as organizational design, organizational structure, organizational effectiveness, and many others are likely to reveal insights into issues related to collective performance, its retention under different circumstances, and approaches to the study of organizational issues. The discussion that follows only scratches the surface, without the benefit of a detailed search in this literature.

Collective structure can vary in the number of levels within the collective, the number of sub-units at each level and the way in which responsibility is divided and communication channelled within this structure. The structure will influence the quality, quantity and pattern of reporting and information exchange among elements in the collective. The architecture of the collective will also define allocation of functions to individual team members and sub-units, and hence the degree of specialisation among them (Paris et al., 2000). The more complex the structure the more knowledge required to construct an effective mental model of the relationships among the elements, and the more difficult retention will be. In turn, this is likely affect some of the task factors discussed in the previous section, such as co-ordination and re-deployment of resources, timely and appropriate exchange of information, and others.

Depending on the needs for information exchange and co-ordination, more highly differentiated collectives may provide more communication barriers, necessitating more complex communication procedures. This increases the probability that key information will either fall between the cracks or be in error, affecting co-ordination of the collective task.

Using collective structure to predict collective skill retention is prominent in a model created by Roth (1992). Roth explored several different forms of military units and, in part, used the structure of these units to predict how the collective skills might decay. In the Roth model, the related concept of "hierarchical leadership" was given the most dominant influence. Roth argued that the relative proportions of senior leaders, junior leaders and non-leaders were important predictors of collective skill retention. While this may be true, it is likely only a small part of the story with respect to the influence of collective structure on retention of collective performance.

Predictions for retention of collective performance:

- Collective performance will decay more quickly in collectives with a more complex organizational structure in terms of sub-units and levels of authority.

### 5.2.2 Size of the Collective

As the number of people in collective increases, the decay of a collective skill is also likely to increase (Roth, 1992) for two reasons. First, collective skill retention may decrease as a simple consequence of individual decay functions aggregated across multiple people. Secondly, with increasing numbers comes an increased demand for communication and co-ordination among members and sub-units of the collective. Greater complexity is associated with faster decay, other things being equal. Size is also likely to be related to organizational complexity.

On the other hand, as argued above, depending on the structure of the collective and the distribution of skills, sub-tasks and communication channels, and the level of redundancy in membership, increased size may be associated with increased resilience of collective memory to counter instances of decay in individual skills, an increased capability to compensate for errors, and better redistribution of spare resources to adapt to change. This would argue for an increase in retention of overall performance associated with increases in collective size.

There may also be other relationships between collective size and retention of collective performance. In very large groups, for example, the phenomenon of "social loafing" is common (Karau and Williams, 1995). Social loafing occurs when individuals fail to put in their best effort, presumably in the belief that other members of the group will "carry the load". Within very large collectives, a diminished sense of personal accountability and responsibility may impact on the retention of complex skills. In large collectives, lower levels of personal accountability and responsibility may negatively influence the desire or ability to maintain relevant skills, causing collective performance to erode more rapidly.

Another factor related to size will be internal personnel turbulence (e.g. promotion, or re-assignment inside the collective) and external personnel turnover (departure from the collective service for any reason). The smaller the team or group, and the longer its prior membership, the more disruptive turbulence and turnover is likely to be in terms of retention of collective performance. This issue is discussed in a later section.

In the end, overall collective size, per se, may matter less than the interacting factors within the collective, for instance, the size and structure of its sub-groups and the consistency of the motivational environment within and between those groups. Nevertheless, with other things held equal, it seems most likely that an increase in collective size will reduce retention of performance in overall collective tasks.

Predictions for retention of collective performance:

- Increases in collective size will reduce retention.

### 5.2.3 Leadership structure

Leadership issues may be regarded in terms of quantity and quality.

In quantitative terms, Roth (1992) discusses the number of leader positions in a collective, as related to the number of sub-units and teams. Leadership positions are regarded as focal points of greater knowledge of collective sub-tasks and interactive skill sets in the collective, the loss of which would be particularly detrimental to the performance of collective tasks. The more leadership positions there are, Roth argues, the less impact there will be as a result of the loss of any one.

On the other hand, more leadership positions will be correlated with a greater number of sub-groups within the organizational structure. Earlier, greater organizational complexity was argued likely to inhibit retention of collective performance. This suggests that there may be an optimal number of leaders in relation to other features of collective tasks and structure, above and below which collective performance may be negatively affected.

In qualitative terms, leaders are likely to know more about their subordinates tasks and how they interact, and possess the interactive skills (and be tasked) to detect and overcome any decay in their subordinates skills by prompting them or compensating for the deficiency in some other way, for example re-deploying resources directly within that team, or communicating the need to others in the collective.

Leaders are also likely to possess interactive skills necessary for co-ordinating and otherwise facilitating performance on collective tasks. For example, creating an atmosphere of excellence, for example, may increase the motivation to maintain skills at an individual as well as collective level. Decay in such interactive skills among those in leadership positions can be expected to have a disproportional effect on collective performance. For similar reasons, turnover among those in leadership positions can be expected to have a greater impact on retention than turnover among other positions.

Predictions for collective skill retention:

- Decay in interactive skills among those in leadership positions will have a greater negative effect on collective performance.
- Too many or too few leadership positions will negatively affect retention of collective performance.

### 5.2.4 Role substitution

The term "*role substitution*" refers to the potential ability of members of a collective to swap sub-tasks and still perform them effectively. This concept seems closely related to the idea of interchangeability of collective sub-tasks. Effective swapping assumes common knowledge and skill in relation to both the collective membership and the requirements of collective sub-tasks. Roth (1992) uses the term "*position redundancy*" and considers the potential for such role swapping an important predictor of improved collective skill retention. Dieterly (1988) distinguishes "*task redundancy*" (the ability of more than one team member to perform a sub-task) from "*individual redundancy*" (added team members act as back-up for high risk critical tasks). Dieterly associates task redundancy with increased system reliability. Dieterly also discusses related task dimensions such as "*position uniqueness*" (where a task can only be accomplished by one position in the team) and "*task uniqueness*" (a sub-task that must be completed for completion of overall collective task). Taken together, Dieterly uses these concepts to formulate predictions of team performance.

When the potential for role substitution is high, individual skill decay is likely to impact less on the performance of the collective as a whole since other members of the collective will be likely to have retained the skills and knowledge necessary to prompt others or to perform the task themselves, or to identify degradation of the relevant skill and the need to do something about it.

Within collectives, the potential for role substitution will vary according to the level of specialisation of its members, overlap in the skill requirements of sub-tasks, and sub-task and personnel redundancy in the collective. Where collective members have more specialized skills and/or the collective sub-tasks require specialized skills (two things that seems likely to go together), substituting will be more difficult. If there is no redundancy in terms of tasks or personnel, re-deployment to achieve role substitution may leave functional holes elsewhere in the organization.

At the level of the tank crew, for example, the role of driver is very distinct from the role of gunner (Keesling, 1995) and it is difficult to imagine the driver substituting for the gunner. When roles are less tightly constrained and individual skills more generic across the collective in relation to the task to hand, as for example when preparing an infantry defensive position, swapping may be easier. In such cases, other members of the collective can pick up the slack caused by decay in sub-task performance by individuals, and maintain overall performance of the collective.

Thus, the likely effect of role substitution will interact with the presence of generic skills among collective members, the degree to which the overall collective task permits application of such generic skills, and the capability of the collective to detect a problem and re-deploy its resources appropriately.

Although no direct support was found for the assertion that role substitution will enhance the retention of collective skills, indirect evidence suggests that cross training enhances team performance. Cross-training, for example, requires team members to temporarily swap roles with other team members. The goal of cross-training is to provide all team members with an understanding of the entire team function and how one's particular tasks and responsibilities interrelate with those of other team members. This information about other team members includes appropriate task behaviours, as well as the roles and the responses required by the team mates in varying situations, and allows for accurate prediction, anticipation of information exchanges and co-ordination with other team mates. The more cross training conducted by members of a team or collective, the greater the assumed sharing of team mental models.

Volpe et al. (1996) examined cross-training among two person crews for a simulated air combat task. Without cross training, participants received conventional individual training relevant only to the specific function that they needed to perform. With cross training, participants learned both about their own specific responsibilities, and about those of the other team members. Teams that were cross-trained performed better at their own task, communicated more effectively, and were better able to work as a team or collective. McCann et al. (2000) examined cross-training in three person teams conducting naval surveillance and contact identification tasks and found that cross trained teams did not show a decrement in speed or accuracy of performance as a result of unexpected reconfiguration (role substitution) within a team, while teams without cross training did.

While this work relates only to very small collectives or teams and does not speak directly to the issue of retention of collective performance, it does suggest that a higher potential for role substitution may be related to less decay in collective performance.

Predictions for collective skill retention:

- Increased potential for role substitution will improve collective skill retention.

### 5.2.5 Team Mental Models

Mental models are typically described as organized knowledge structures that allow individuals to predict and explain the world around them, to recognize and remember relationships, and to construct predictions of what is likely to occur (Mathieu et al., 2000). Research has begun to address the extent to which individuals construct and share similar mental models when working as a team (Langan-Fox et al., 2000). Effective team performance is held to require multiple shared models (Cannon Bowers et al., 1993; Mathieu et al., 2000) comprising topics focussed around:

- *Collective tasks and sub-tasks:*
  goals, strategies, procedures, dependencies, contingencies, criticality.
- *Team interaction:*
  role responsibilities, interdependencies, information channels.
- *Team membership*:
  Other team members knowledge, skills, capabilities.
- *Environmental factors:*
  Equipment, terrain, climate, organizational culture.

In short, shared mental models allow team members to be "on the same page" in pursuit of a common goal. Shared mental models have been argued to improve team performance (Langan-Fox et al., 2000). Mathieu et al. (2000) shows that a higher level of overlap among team members' mental models is associated with higher levels of performance, and that this effect is mediated by team

processes such as communication and co-ordination. Cross training is one method of enhancing shared team mental models.

Although no research was found to directly support the assertion that shared mental models improve retention of collective skills, this seems likely. Shared mental models of the team membership should improve anticipation and correction of decay in individual skills. Shared mental models of the task should also enable collective members to substitute for each other more effectively and co-ordination within the collective should be more resistant the decay.

Decay rates of different knowledge components of team mental models are likely to interact with other aspects of collective structure, collective tasks and events occurring during the retention interval. For example, increased turnover (people leaving the collective entirely) will affect knowledge about team member capabilities. Increased turbulence (position changes within the collective) may be the equivalent of cross-training and improve tacit knowledge of other team members' tasks. More complex collective structures and more interdependent tasks will increase the complexity of the knowledge required to be retained for the mental model, and increase decay rates. Other potential interactions need to be considered in detail.

Predictions for retention of collective performance:

- More comprehensive shared mental models for the collective and the collective task will improve skill retention.
- More complex mental models will decay more rapidly.

### 5.2.6 Turnover and Turbulence

Two, related, sources of changes in collective personnel can be distinguished.

- turnover (departure from the collective service for any reason).
- turbulence (e.g. promotion, or re-assignment inside the collective)

High rates of turnover is a particular problem in many military collectives. Loss of technical specialists with better job prospects outside the military becomes a particular challenge as dependence on complex technologies increases.

When collective members leave, they take with them knowledge about how to accomplish a collective task. They may be replaced by a newcomer, or by changes made within the collective. The newcomer may bring experience or capabilities that adds value, or vice-versa. Newcomers may reduce collective task performance until replacement(s) learn their individual and interactive tasks, in the context of the current collective membership. Even in the best case, collective task performance is likely to diminish during the readjustment. Roth (1992) believes that, in general, turnover can be equivalent to an entire month without practising collective skills, although the basis of this belief is not clear.

The impact of turnover on collective skill retention can be expected to interact with size of the collective, the role of the collective member, and the skill and experience of the substitute. Within a small 3 person team, for example, the departure of one team member on collective skill retention will likely be greater than would turnover of one private within an infantry company, turnover among leaders could be expected to be greater than non-leaders.

A closely related issue in the literature concerns changes in the roles and responsibilities of collective members, or collective turbulence. When unit members change the positions that they occupy within a team, the tasks they perform are also likely to change. Such turbulence frequently occurs in response to

staff leaving or joining the collective, and for promotions. Team members must then readjust learn their new roles and responsibilities (Keesling, 1995).

However, if turbulence is regarded as the equivalent of cross training, then a positive effect can be expected with respect to shared mental models among the team and the potential for role substitution. For example, for three person naval surveillance team tasks, McCann et al. 2000 compared cross training with no cross training within a standardized training period with two results. First, level of speed and accuracy achieved by the team without cross training exceeded that of the team that received cross training. This result was explained by the increased training time per position received by each team member in the no cross training condition. However, when turbulence occurred (i.e. within each team, positions were unexpectedly swapped), cross trained teams showed no decrement in speed or accuracy, while the teams without cross training showed an appreciable decrement. An implication of this is that if the cross trained teams had as much practice in each position as teams without cross training, turbulence may have had no effect on performance, and final performance levels may have been high.

Thus, while there may be a period of deterioration in performance shortly after a period of turbulence, in the longer term, some degree of cross training among collective members may actually reduce skill decay, as well as provide other benefits described in the section on shared mental models.

The long term effect of both turnover and turbulence on retention of collective skills is likely to interact with levels of task interdependence and the potential for role substitution in the collective. Below a certain point, turnover and/or turbulence may have promote a positive cross training effect and help hold decay in collective performance at bay. At very high levels, the impact of turnover may become entirely negative, since there will be no basis for role substitution or shared mental models – because nearly everyone is new.

Predictions for collective skill retention:

- The effect of low rates of turnover on skill retention will depend upon mental models, individual and interactive skills of the replacements.
- The effect of high rates of turnover will be to reduce collective skill retention.
- Turbulence will increase shared mental models and, in the short term, reduce collective performance but, in the long term, improve collective skill retention.

### 5.2.7 The social environment within the collective

Concepts such as corporate culture, common intent, social dynamics, trust, team potency, and others are concepts that are supposedly related to collective performance, and potentially retention of collective skills.

A positive social milieu can be expected to impact collective skill retention in different ways. McCallum et al. (1989; cited in Swezey and Llaneras, 1997) studied 13 teams of 8-12 members (and found that effective teams exhibit behaviours that reinforce effective performance, communicate more, provide feedback and help where performance is lacking, and exhibit more co-operative behaviours. Dieterley (1997) cites a taxonomy of team functions by Shifflet et al. (1982) that includes motivational functions such as development and generating acceptance of team performance norms, establishing team level performance rewards, reinforcement of task orientation among team members, balancing team orientation with individual competition and resolution of conflict. Others (e.g. Amazon and Sapienza, 1977; Knight et al., 1999) distinguish effective management teams in terms of their ability to both resolve and make use of affective and cognitive conflict.

Such aspects of the social environment are likely to result in higher initial levels of individual and interactive skills, generation of more comprehensive and reality based shared team mental models, and an increased potential for role substitution. Since higher initial performance levels are likely associated with longer skill retention in collectives as well as individuals, it is a short step to conclude that teams or collectives with positive social attributes such as the above will exhibit better retention of collective performance.

Predictions for collective skill retention:

- The presence of positive social attributes within collectives is likely to have a strong positive effect on skill retention.

### 5.2.8 Summary of Features of the Collective

In some instances, features of the collective are difficult to distinguish from features of the task or the characteristics of individuals. As size of the collective increases, then its structure in terms of sub-groups and their specialisation becomes more closely linked to the nature of the collective task. The structure of collectives will be related to the number, type and diversity of tasks it is expected to perform. Are shared team mental models best considered attributes of the individual or the collective? Is leadership best described in structural terms of the collective (the number of sub-groups and the ideal span of control / supervision leaders), or in functional terms in relation to the needs of the collective task with respect for particular levels of effort in different areas of specialisation, or in qualitative terms in terms of the attributes required by those in leadership positions.

A further complication is that many features are interdependent and/or likely to have inflection points, above and below which the positive or negative nature of the effect may change. Teasing out the relative effect of different factors in relation to others is likely a Gordian knot, susceptible only to broad and relative crude solutions at the current state of knowledge.

## 5.3 Characteristics of individuals forming the collective

Individual differences are seen by some as an impossibly complex factor. Developers of the UDA model, for example, eliminated consideration of individual factors due to practical problems of measurement (Rose et al., 1985a). We believe the role of individual differences deserves to be revisited at both the individual and the collective level.

The section covers characteristics of individuals forming the collective, as follows:

- Individual Aptitudes
- Diversity of experience
- Experience in collective settings.

### 5.3.1 Individual Aptitude

Individual aptitude is frequently cited in the literature as a predictor of individual skill acquisition and retention (e.g. Hagman and Rose, 1983) but also as a major difficulty in deriving general laws of acquisition (Powers, 1976; cited in Swezey and Llaneras, 1997). For skill retention, the aptitude of interest is typically identified as aptitude for learning.

Although different individual aptitudes are consistently related to different acquisition curves under a single method of training, these curves can become more similar when training is customized to

individuals (Cronbach and Snow, 1976; cited in Swezey and Llaneras, 1997). High ability students, regardless of method of instruction, typically have higher initial performance levels and, consequently, slower rates of improvement (and perhaps slower rates of decay). The result is often instability in acquisition data, especially in the early stages of complex skill acquisition, likely attributable to large within-subject variations in aptitude and initial performance levels, differences in rates of skill acquisition, and differences in learning rates across the various stages of learning. There is no reason to suppose that skill retention is any less complicated and difficult to unravel, especially when multiple individuals are concerned at the level of the collective.

Not surprisingly, therefore, the relationship between aptitude and skill retention is unclear (Sabol and Wisher, 2001). Some evidence suggests that aptitude on its own does not predict individual skill decay, as the rate at which high and low aptitude individuals show skill loss has been shown to be fairly consistent (Hagman and Rose, 1983). Other evidence suggests that high aptitude individuals can achieve over-learning easier than can low aptitude individuals (Sabol and Wisher, 2001) and over-learning is frequently cited to promote better individual skill retention (e.g. Hagman and Rose, 1983). This would suggest that higher aptitudes would have be associated with better retention. Although it not been tested within a collective context, Roth (1992) suggests that individual aptitude should be considered in future collective models. Probably future work should consider both average and individual levels of aptitude within a collective unit, especially for interactive skills critical to performance of collective tasks with interdependent sub-tasks (likely most collective tasks) and for complex specialized individual skills required for sub-tasks shown to be on the critical path for any given collective tasks.

Individual interactive skills such as co-ordination and communication deemed important for collective performance and retention, may, to a some degree, be equated to leadership skills. Leadership skills have always been seen as important in the context of military collectives but to a large extent are believed to be acquired by tacit on the job learning (Horvath et al., 1994a, 1994b). If this is true, then learning aptitudes will be particularly critical for acquisition tacit interactive skills and, hence, influential in determining collective skill retention.

Classifying tasks into taxonomies according to underlying skill requirements is a common approach for many issues in training. For example, Driskell et al., (1992; cited in Swezey and Llaneras, 1997) have distinguished between physical and cognitive/knowledge task components, with different acquisition and retention characteristics. Different classification approaches include those which organize task requirements, and those which organize presumed learning processes underlying task performance, often based on task analytic methods (Gael, 1998). For instance, Dieterly (1988) outlines Schifflet et al.'s (1982) taxonomy of team functions as follows.

| Function | Item |
|---|---|
| Orientation | 1. Information exchange regarding members and resources<br>2. Information exchange regarding team task and goals / missions<br>3. Information exchange regarding environmental characteristics and constraints<br>4. Priority assignment among tasks. |
| Resource distribution | 1. Matching member resources to task requirements<br>2. Load balancing |
| Timing or pacing | 1. General activity pacing<br>2. Individually oriented activity pacing |
| Response co-ordination | 1. Response sequencing<br>2. Time and position co-ordination of responses |
| Motivation | Development of team performance norms.<br>Generating acceptance of team performance norms.<br>Establishing team-level performance-reward linkages<br>Reinforcement of task orientation<br>Balancing team orientation with individual competition<br>Resolution of performance-relevant conflicts. |

**Table 3: Taxonomy of Team Functions (from Shiflett et al., 1982)**

It is likely that taxonomies or aptitude profiles for interactive team work skills already exist. If so, it would be worthwhile to investigate the relationship such profiles with the speed, acquisition and retention of interactive and teamwork skills, and acquisition and retention of performance on selected collective tasks.

Thus, for collective tasks, indicators of aptitude should be broadened to include more than just aptitude for learning of individual sub-tasks. Individual differences in interactive skills such as the ability to co-ordinate and communicate with others are also likely to predict the long term retention of collective skills. Such a distinction is prominent in the team work literature's description of task work and teamwork (McIntyre and Salas, 1995).

Predictions for retention of collective performance:

- Higher aptitude for learning tacit interactive skills and elements of team mental models will be related to better retention of performance on collective tasks.
- Higher aptitude for individual specialist skills on the critical path for collective tasks will be related to better retention of performance on collective tasks.

### 5.3.2 Diversity of Expertise

Diversity of expertise in a collective will be related to level of specialisation required by different sub-tasks in the collective task, and the organization of sub-groups within the collective structure. At the individual level, greater diversity of specialisation with small groups, at whatever level in the organization but most studied in relation to management teams or product or software development teams, has been related to greater levels of cognitive and affective conflict (Amazon and Sapienza, 1977), and as providing obstacles to information exchange and fusion in pursuit of solutions to collective problems requiring integration of diverse expertise. These difficulties arise often because of barriers to comprehension across different knowledge domains, or real or perceived differences in the motivation or competence of other individuals or sub-groups (e.g. Knouse, 1996; Stenger, 1997).

Oversimplifying, the key to overcoming such challenges in pursuit of collective goals is often cited as possession by group leaders of superior interactive or facilitation skills (Amazon and Sapienza, 1977). The probable importance of such skills to collective performance has been already noted several times.

Another likely influence is the duration of the group – those groups with longer durations are more likely to expend the effort needed to learn to work together, as well as having more opportunity for tacit learning about capabilities of other team members. Especially at the level of larger collectives, or multi-arm, joint service, or multi-national collectives, medium size collectives may be convened at relatively short notice with little experience one of the other to perform collective tasks for which they have been trained only in isolation one from the other. (Historically this has been so, and current or recent operations in the Balkans and in Afghanistan would also seem to support this). In fluid long term operations, collective tasks at, say the battle group, brigade or naval task force level, may be formed from diverse and specialized sub-units with little direct experience one of the other.

Collectives with great diversity in expertise among their members or sub-groups are likely to have more difficulty maintaining a common view of the task, may be less likely to maintain skills outside their own area of interest, and find communication, information exchange and task co-ordination, particularly for sub tasks that resist proceduralization, more challenging. This would suggest that higher levels of diversity in expertise would predict lower levels of collective skill retention.

Predictions for retention of collective performance:

- Greater diversity of expertise within the collective will be related to less retention in collective skills.

### 5.3.3 Experience in Collective Settings

The experience of collective members may be thought of in different ways: prior to joining the collective; prior to training on the collective task(s); during the retention interval. Also, there are different ways in which such experience may relate to retention of performance on collective tasks. For example, through the positive or negative transfer of training from past experiences to present performance or by adding to the repertoire of knowledge and skills available within the collective, thereby enhancing the potential within the collective for error recovery or role substitution. The degree of similarity of shared experiences among collective members may also contribute to sharing of mental models among collective members to a greater or lesser degree. The degree of similarity might range from being in the same collective performing the same collective task performing the same sub-task under similar conditions, to being in a similar collective but with different people, performing a different collective task or a different sub-task, under dissimilar conditions. The permutations and combinations would be many, some aspects may be key. One likely one, often cited anecdotally, is experience of actual combat.

Pigeau and McCann (1995, 2000) assert that common intent (believed especially important for achieving collective goals as represented by command intent when planning and procedures fall apart under the fog of war) is achieved among members of a collective largely as a result of shared experiences with other members of the collective as well as learning held in common, perhaps stretching back into common cultural antecedents to military experience. The basis of regimental tradition claimed to underlie excellence in military performance (Winslow, 1998) is generated, to a large extent, by stressing the common history among members of the regiment and having members of the regimental "family" stay in or return to the regimental collective whenever practicable. (Witness the protests whenever downsizing forces formerly separate British regiments to combine.)

There are many reasons to suppose the cross section of experience among collective members of collective tasks might impact on skill retention. Greater experience performing collective tasks may result in over-learning of some components of interactive skills, making these skills more resistant to forgetting. Experience working (or playing) with others, provides the opportunity to develop the knowledge structures needed to attend to the cues and information provided by other team members, either as generic skills, or to build mental models of particular members of one's own collective. For example, participation in team sports systematically organized to build networks across smaller units in the wider collective will help build different aspects of team mental models, and, presumably, enhance ability to predict how others will respond and lead to better performance on future collective tasks.

There is theoretical agreement that teams who work together for longer periods of time will show higher levels of performance (McIntrye and Salas, 1995) but we are not aware of any empirical evidence that collectives in which members have broad experience working together (or as a members of other collectives) show retain collective performance better, though it seems likely. However, such concepts are likely to have been examined in the literature on occupational and organizational psychology, and merits more thorough investigation than has been possible in this project.

Predictions for collective skill retention:

- For individual skills, the effect of previous experience in collective settings and with collective tasks will depend on the transfer of training between those experiences and the collective task of interest.
- Shared experiences of collective settings and collective tasks among collective members will contribute to the shared mental models of team members. The effect on collective performance will depend on the degree to which the elements of the sha ed team mental model match the collective membership, context, and task of interest.

### 5.3.4 Summary of Individual Factors

Particularly among leaders of sub-groups within collectives, individual differences in aptitude for learning tacit interactive skills and knowledge components of team mental models as well as differences in individual skills associated with performance of sub-tasks on the critical path of collective tasks, are likely strong contributors to both acquisition and retention of performance on collective tasks. Diversity of expertise among collective members will likely be related to collective structure, in terms of sub-group functions. Co-ordination of the efforts of very diverse speciality sub-groups and pooling of expert knowledge among the leaders of these sub-groups will present a challenge to acquisition and retention of collective performance, especially in situations where pooling of knowledge is required for problem solving, or when situations change during the performance of the collective task. Experience in collective settings may enhance or interfere with collective performance, depending on whether there is a positive or negative transfer effect between the experience(s) in question, or the degree the experience is held in common and contributes to the shared mental model of the different elements of collective functioning.

Overall, individual differences among collective members are likely to play a prominent role in retention. Despite their complexity, relevant aspects of occupational and organizational merit further investigation with respect to their application potential for prediction of collective performance and retention.

## 5.4 Features of the training received by the collective

Training issues relate to the nature and focus of training received by individual collective members in individual and interactive skills, and the training that the collective receives as a whole in the collective task of interest and in other collective tasks (before or during the retention period), the effects of which may transfer positively or negatively to overall collective performance on the task of interest.

The section covers the following features of training received by the collective:

- Level of learning after initial training
- The match between the training context and the retention context;
- Training received as a collective;
- Training approaches used to achieve collective performance.

### 5.4.1 Level of learning after initial training

For individual skills, the degree of initial learning as a result of training has been argued to be one of the most important predictors of skill retention (Sabol and Wisher, 2001; Spears, 1991a; Bodilly et al., 1986; Farr 1987). The greater the initial learning, the slower the rate of forgetting. This effect is so strong that some argue that anything that leads to higher levels of initial learning will strengthen skill retention (Swesey and Llaneras, 1997). Differences among individuals in terms of original learning seem more powerful determinants of retention than differences in forgetting. This effect has held in a wide range of contexts including motor, procedural and verbal learning (Swezey and Llaneras, 1997) and armour skills (Rowatt and Shlechter, 1993). Retention can be expected to improve where there is increased practice beyond mastery to induce over-learning, and when learners are required to overcome instances of contextual interference or provided with opportunities for deeper processing that results in better organization of material for later retrieval. This leads to the suggestion that evaluation of the training methods used may be an effective method of predicting retention in combination with measurement of performance on completion of training.

However, there is increasing emphasis of the importance of distinguishing between acquisition and learning, and identification of the apparent paradox that training conditions that maximize longer retention and greater resistance to altered contexts may not result in result in maximum performance during acquisition (e.g. Schmidt and Bjork, 1992). Thus the strategy of using end of training evaluations to predict performance on the job or outside the training environment may not be appropriate, with implications for validation of approaches to predicting collective skill retention. This raises the question of just how should skill retention be measured. This methodological issue is addressed in a later section.

These observations are likely to apply to the learning of collective tasks in two ways. First, individual learning of skills critical to the collective task and of interactive skills (e.g. skills related to co-ordination) are likely to respond in a similar manner. Secondly, there is the issue of performance on the overall collective task. Presumably, training strategies can be conceptualized in the same way for collective tasks whereby increased practice will lead to over-learning and contextual interference will lead to better internal organization of mental models with much the same overall effect on the collective as on individuals, provided collective membership remain the same, in the same positions (i.e. turnover and turbulence are low). In the context where there are limited training resources, the question arises whether repeated practice or contextual interference training is more effectively focussed on critical individual skills, individual interactive skills, or training of the collective task(s) as

a whole, and which strategy will lead to better retention of performance on collective tasks, under field conditions. This appears to be an open question.

Predictions for retention of collective performance:

- Performance after initial training of individual skills related to critical collective sub-tasks or to interactive skills may not predict long term retention of those skills.
- Training strategies such as increased practice beyond mastery, contextual interference, or internal elaboration will be related to better retention.

### 5.4.2 Match between Training Context and Retention Context

Transfer of training is closely related to many training issues and factors affecting positive or negative transfer of training influence individual skill retention. Transfer of training refers to the way that previous or intervening learning affects new learning or subsequent performance: in particular, how well initial learning transfers to new situations. The effect may be to inhibit performance (negative transfer) or improve it (positive transfer). This issue lies at the heart of the measurement of retention: i.e. testing after training and re–test after a prescribed interval or intervals. Some believe that, despite enormous sums of money spent on industrial training, possibly as little as 10% actually transfers to on the job performance (Swezey and Llaneras, 1977).

Over-simplified, transfer of training is thought to relate to the degree of similarity of the two situations and the two responses required. The match between training and retention is directly related to the number of cues present in the retention context that assist recall of information learned during training. However, most complex situations resist measurement in such terms. The components of a complex situation can be considered, like collective tasks, to comprise sub-tasks, among any of which there may be different levels of transfer. Swezey and Llaneras (1977) use the example that, overall, positive transfer between every component of one aircraft and another except one critical one, might still result in an unacceptable deterioration in overall performance. Much the same difficulties apply to collective tasks.

A common assumption has long been that the greater the match or fidelity between the training simulator and the operational environment, the greater the likelihood of a positive transfer of training for individual skills. The match between training and retention context is also directly related to the number of cues present in the retention context that will assist in the recall of information learned during training.

More recently, the effectiveness of exact physical fidelity has been questioned. Interest has turned to consider the importance of the learning support provided and instructional approaches. In some cases it is argued that exact physical fidelity limits the use of training strategies known to increase transfer or retention such as corrective feedback, or that the complexity often inherent in a high degree of fidelity distracts and confuses learners. This trend has been accompanied by a distinction between physical and psychological fidelity: the degree to which the trainee (or trainees in the case of a team or collective) perceives the training medium as duplicating the equipment and or the task situation. Some propose that qualitative differences in the degree of fidelity according to the stage and type of learning. Early procedural training benefiting from low fidelity, initial skill acquisition needing greater fidelity in terms of equipment and the context, and finally skill acquisition needing not only the highest level of fidelity, but also the greatest degree of contextual variety (Swezey and Llaneras, 1977).

An implication for skill retention may be that the test – retest conditions should take into account the stage of training to which the collective task has been taken. For larger collectives, it is likely that

training at the whole collective level is so infrequent, that the collective as a whole will not have progressed beyond an intermediate stage of learning, and that skill retention should be considered only as a springboard from which to launch training aimed at preparing for a specific mission. This suggests that collective skill retention models should take progression across different levels of learning in relation to type of maintenance training rather than just final operational learning targets.

For collectives, factors affecting transfer of training are likely to be important predictors of collective performance. Because of the size of most military collectives much training done as a collective is done in the field, making it impossible to retest in exactly the same environment in which training occurred. However, as access to distributed simulators increases, then the potential for controlling the conditions under which collective tasks are trained and assessed may permit the impact of such factors to be better evaluated. In fact, simulator training may, for some high risk or high expense, collective tasks, represent a more realistic and less expensive way of training collectives. An example might be the training of warship operations room teams to respond to multiple air and surface threats under realistic engagement conditions, without the expense of sending ships to sea and using simulated rather than real weapons such as anti-ship and anti-aircraft missiles. (Note also the earlier comment about the potential utility of navy team training simulators.)

One approach to measuring transfer of training holds some interest for predicting retention. This is the simulator evaluation approach proposed by Adams (1979). As described in Swezey and Llaneras (1997), this appears similar to a verification approach, in that the effectiveness of a simulator can be predicted by the degree that it possesses features and its use adheres to scientific principles of training. Much the same principle might be advanced for predicting retention of collective performance: i.e. the degree to which the combined training of critical individual skills, interactive skills and team work has adhered to appropriate training principles known to promote retention.

As in the case of individual skill retention, the interval between when skills are trained and used is an influential predictor of skill retention. Time without training is typically argued to promote the decay of skills by breaking down the cognitive, perceptual or motor processes which underlie the performance of skills, or by making it more difficult for these processes to be either accessed or performed. For collective tasks, we would expect time without training to impact not only on levels of individual skill, but on the ability to perform these skills as a member of a interdependent collective. The length of retention interval can be expected to interact with type of experiences undertaken during it since these may strengthen or interfere with retention to the degree those experiences act as further practice or not.

There been very little research on the impact of retention interval on collective skill retention (Roth, 1992). Work on a limited number of collectives suggests an average of 11% decrease in performance after one month without practice or training on the collective tasks identified, but clearly more work is needed to expand knowledge in this area.

Predictions for retention of collective performance:

- Intervening or test conditions equating to negative transfer of training will reduce retention.
- Intervening or test conditions equating to positive transfer of training will improve retention.
- Longer retention intervals will reduce retention.

### 5.4.3 The training received as a collective unit

Two aspects of training as a collective unit can be considered: training on the target collective task, and training on other collective tasks before and during the retention interval.

While training on the target collective task will probably have the greatest benefit, training as a collective, in whole or in part, on other collective tasks can be expected to have some transfer effect depending on the overlap between the tasks. Working (or playing) together with other collective members on other tasks can be expected to contribute to interactive skills, to the building of mental models about the capabilities of other collective members with respect to critical individual and interactive skills that contribute to given collective tasks (Mathieu et al., 2000).

Some individual and interactive knowledge skills that contribute to the collective task can be learned, to some level, in isolation from other collective members, or by working on other collective tasks. However, training together as a collective on a particular collective task not only allows permits further practice and confirms the capability of the collective to perform the task to the required standard, but adds a team work dimension.

When collective members train together, they practice not only the individual steps in their own sub-tasks and the steps in the collective task, but also learn to work together, to exchange information effectively and co-ordinate their actions, and to know what to expect from their team-mates. This will be particularly valuable to two classes of collective member: those performing interdependent sub-tasks and those responsible for co-ordinating within and between sub-groups within the collective. Time critical sub-tasks, and sub-tasks involving extensive information exchange and interaction among collective members will also benefit from training or practice as a collective.

With each added level of organizational complexity, the task of sub-group co-ordinators can be expected to change. For example, when a basic unit such as a tank crew operates in isolation, the crew commander is responsible primarily for his/her own individual sub-task, and for co-ordinating the tasks of the other crew members in relation the goal of the tank. As other levels of organization are added to the collective (other tanks, infantry, engineers, artillery, fast air), the co-ordination and tactical challenges of the crew commander increase and multi-tasking becomes more necessary, leaving the leader with less cognitive capacity to cope with the task at hand than when the tank crew operated in isolation. Dealing with the consequences of added organizational complexity are difficult to learn in isolation, and tacit learning will be required.

Thus, as the number of levels or sub-teams in a collective increase, the benefit of training together will increase. Individual skills on the critical path and interactive sub-tasks can be practised more realistically as a collective. Multi-tasking strategies required for co-ordination across several organizational levels can also be learned. Many aspects of team mental models can be refined, or developed: particularly those relating to the performance capabilities of other collective members. Tacit learning will occur.

However, there is an important caveat: the degree of learning that occurs is likely to depend on the instructional strategies employed, and the stage of learning reached by individuals or sub-groups with respect to knowledge of the collective task, as well as individual and interactive skills. Simply practising together as a collective on the collective task may not always have any learning impact. For instance, it is likely that learning as a collective progresses through stages much as individual tasks. If this true, in terms of fidelity, for instance, early conditions of training on a collective task should not be too realistic, or some or all collective members may become confused as a result of too much complexity, and learn little – much in the same way as learning of individual skills can be inhibited if too much fidelity is introduced too early. Likewise, practise without detailed knowledge of results and

corrective guidance, is unlikely to result in learning or, worse, may result in learning the wrong lessons.

Given the relative infrequency of training as a collective, particularly for larger collectives, it is possible that the level of learning achieved for a given collective task may not have ever progressed beyond the initial associative stage, or the intermediary procedural knowledge stage, and that the autonomous stage dependent on frequent extra practice will not have been reached. For managing training strategies, knowing the stage to which learning on collective tasks or sub-tasks has progressed is critical in predicting decay. To estimate the stage of learning achieved, an estimate transfer of training from one type of collective activity to another, with respect to the different individual skills and knowledge required for performance of the collective task, may be more meaningful than the number of times a particular collective task has been practised.

In conclusion, we would expect that a collective that trained as a unit would maintain their performance as a collective better over time than collectives that did not, but that the degree of impact will depend on the qualitative as much as the quantitative nature of that training.

### 5.4.4 Training approaches used

Training approaches are probably best formulated on the basis of a task analysis (Gael, 1988), but there seems little consensus in the literature about how to analyse team or collective tasks as a prelude to design of training programs.

Any such analysis would need to identify the skill requirements of collective sub-tasks, their position on the critical path for the collective task as a whole, the interdependence of critical sub-tasks, and the nature of the individual and interactive skills required by different positions in the collective. The nature of the equipment employed in the performance of those tasks, and the range of conditions under which the collective task might be conducted would also need to be taken into account. From this analysis could be determined the individual, interactive and team work knowledge and skills most likely to affect collective performance and the training approach best suited to their acquisition and retention.

If, for instance, the collective task requires little co-ordination, and a lot of physical strength and endurance on the part of all collective members, then retention of collective performance might be based primarily on rate of decay of physical capability of the weakest member – and the most appropriate training approach to enhance physical capacity of all collective members.

Based on the degree to which critical team members (maybe defined as those performing critical individual, interdependent, or co-ordination sub tasks) had received the most appropriate training for skill acquisition and retention, some prescription for maintenance or mission training in terms of objectives and approach might be made for the collective task(s) that need to be brought to a state of mission preparedness.

Two levels of training might be considered: maintenance levels and mission levels. Maintenance levels might represent, for a broad range of tasks, a spring board performance level from which a limited number might need to be brought to mission readiness within some defined preparation time.

Swezey and Llaneras (1977) cite research to conclude that acquisition, retrieval and retention all depend to a large degree on how the learning material has been organized and presented. For instance, conceptually or categorically organized material shows less memory loss and better generalisation across different operational situations. Tasks that are easier to organize mentally are learned faster and retained better as does encouraging learners to relate new knowledge to past experiences. When

appropriately organized and customized to the needs of the learner, even complex procedural tasks that normally show lower retention may be retained longer. Instructional strategies that remind learners of currently possessed knowledge and relate this to the new knowledge, make repeated use of information presented from different perspectives, and encourage elaboration of the material during the acquisition and the retention interval, are better retained.

Studies by Schmidt and Bjork (1992) suggest that while block practice may enhance performance at the end of training, random practice shows better retention, even though end of training performance may be reduced. However, in at least one study of small teams, this was not shown (Rhodeniser et al., 1998). In this work, two person teams learned a simulated radar target identification task using massed or distributed practice. Performance measures taken at the end of training and after short retention intervals of up to 7 days showed that a distributed schedule resulted in better skill acquisition but no difference in skill retention, suggesting that different practice schedules may work differently at individual and collective levels. Nonetheless, like much other such work, this study was conducted with an artificial task, and with undergraduate "teams" rather than true collectives used to the domain and to working together.

Techniques that permit learners to build mental models of team and task issues help cue recognition and re-construction of information later and are argued to enhance team performance (Cannon-Bowers et al., 1993).

Training feedback or knowledge of results is frequently cited as a key factor in promoting the acquisition and retention of individual skills (Schendel and Hagman, 1991). Feedback may facilitate skill retention, as it highlights successful performance and provides remedial information about aspects of performance that needs to be corrected. For collectives, there is good reason to believe that effective feedback during training will also be a good predictor of skill retention. It is important to note, here, however, that levels of feedback may be less within collective training environments than in individual training environments, as the sheer number of people is larger within collectives. Knowledge of results and task feedback are seen as important predictors of team performance (Turnage et al., 1990).

One needs to distinguish between uses of the terms *cueing* and *feedback( knowledge of results)*. Cueing or prompting may be described an aid to learning task sequences that should be gradually withdrawn. The term is also used to describe on-the-job prompts to step a user through the task. The value of prompts may vary with the expertise of the performer. A first time user may depend on them as may a skilled user returning to the task after a long absence. Skilled performers may find that prompts interfere with multi-tasking and slow down performance. Feedback is qualitative information about task performance on a task just performed, and may be verbal, sensory, or equipment status related. Longer post task lags in feedback diminish the training benefit of feedback, as do too much or too little detail with respect to the needs of the learner. Feedback can also form a critical item of information for performance of certain types of continuous or interactive tasks, such as tracking targets, or dovetailing one individual collective sub-task with another.

Thus, in teams, feedback becomes more complex. Feedback (or cues) may be provided about task completion by others for interdependent tasks, about whether one's own interactive tasks are being performed appropriately with respect to the others in the collective (e.g. information being accurate and timely).

Although the area of instructional strategy contain many inconsistent or ambiguous results, even for individual skills, and lack a comprehensive theoretical framework, nevertheless, some training strategies can be expected to result in greater retention, at least with respect to individual skills likely to contribute

to collective performance. If the training received by the collective members, individually or together could be assessed, then this can be expected to become an influential predictor of future performance on collective tasks.

Such training approaches might include:

- Cross training collective members in each others tasks.
- Appropriate provision of feedback for key collective tasks.
- Training with other collective members on collaborative tasks that build awareness of other team members capabilities.
- Conceptual organization of material to be learned.
- Using contextual interference to force consideration of working in other contexts.
- Forcing elaboration of cognitive structures.
- Distributed rather than random practice.

Predictions for retention of collective performance:

- The original training approach used for critical and interdependent individual sub-tasks will affect retention.
- Transfer from training on other collective tasks during the retention interval will affect retention.

### 5.4.5 Summary of Training Factors

This section considered the level of learning after initial training; the match between the training context and the retention context; training received as a collective; and training approaches used to achieve collective performance.

Discussion of these factors emphasizes the importance of understanding the contribution of individual sub-tasks to performance on the overall collective task. Achieving this understanding requires some form of team task analysis to assess sub-task interdependence, criticality, the need for interaction among team members, and the knowledge to be shared for an effective team mental model. Then, the knowledge of the effect of individual retention factors can be focussed more diagnostically to predict retention of the collective task as a whole. For instance the degree of over-learning, assessment of learning strategies used to promote retention, transfer of training from other collective tasks conducted during the retention interval, and the degree to which such collective training contributes to tacit learning of knowledge contributing to relevant components of team mental models (such as the capability of other team members), the implications of the stage of learning reached (as individuals and as a collective), decay rates for different types of procedural or knowledge complexity.

Assessment of both the original the approach to training, and related training during the retention interval could then contribute both the prediction of collective retention, and suggest strategies for refresher training.

## 5.5 Overview of Factors

The table below summarizes the factors discussed in this section by category as a preliminary framework for comparison of existing models reviewed in subsequent sections and, eventually, development of new models. The columns on the right of the table refer to the models to be discussed in subsequent sections.

| | | Models reviewed[1] | | | |
|---|---|---|---|---|---|
| | **Factors** | N | ARI-1 | ARI-2 | R |
| **Collective tasks and sub-tasks** | 1. Number of collective tasks assigned to the unit | | | | |
| | 2. Number steps in individual sub-tasks | | | | |
| | 3. Availability of interstep cueing within sub-tasks | | | | |
| | 4. Predictability of sub-task procedures & conditions of performance. | | | | |
| | 5. Number of discrete skills required by the collective task | | | | |
| | 6. Number of sub-units needed to complete sub-tasks | | | | |
| | 7. Interchangeability among collective sub-tasks | | | | |
| | 8. Interdependence among collective sub-tasks | | | | |
| | 9. Potential for error correction and resource re-deployment. | | | | |
| | 10. Need for information exchange among collective members | | | | |
| | 11. Cognitive complexity of collective sub-tasks. | | | | |
| | 12. Time criticality of sub-task | | | | |
| **Collective structure** | 1. Structure of the collective (sub-units and levels of organization). | | | | |
| | 2. Number of people in the collective. | | | | |
| | 3. Leadership structure | | | | |
| | 4. Potential for role substitution | | | | |
| | | | | | |
| **Collective member-ship** | 1. Shared mental models of team members and team tasks. | | | | |
| | 2. External turnover and internal turbulence | | | | |
| | 3. Social environment in the collective. | | | | |
| | | | | | |
| **Individual differences** | 1. Aptitudes of collective members | | | | |
| | 2. Diversity of experience among collective members | | | | |
| | 3. Experience in collective settings. | | | | |
| | | | | | |
| **Training received** | 1. Level of learning after initial training. | | | | |
| | 2. Time since training: retention interval | | | | |
| | 3. Match between the training context and the retention context. | | | | |
| | 4. Training received as a collective | | | | |
| | 5. Training strategies used to achieve collective performance. | | | | |
| | 6. Acquisition phase of collective task | | | | |
| **Other** | 1. Number of items of equipment and their complexity | | | | |
| | | | | | |
| | | | | | |

**Table 4: Summary of factors likely to influence collective skill retention.**
([1]N = Nichols; ARI = Army Research Institute; R = Roth)

Many diverse factors are likely to impact on collective skill retention. These factors relate to the characteristics of collective tasks, features of the collective itself, individual difference factors, training factors, and the interval without training. It is important to re-emphasize that the factors known to affect retention of individual performance are likely to affect retention of collective performance in two ways. First, collective tasks will be influenced in different ways by the performance on individual sub-tasks. Those sub-tasks may be independent, interdependent or require skill at interaction with others. The significance of these sub-tasks must be set in the context of the overall collective task, but to a great extent, retention can probably be treated individually. Second, and less likely, factors affecting retention of individual tasks may work in much the same way on overall retention of performance of collective tasks. Complex interactive factors are likely to complicate the picture even further than in the case of retention of individual performance.

It remains to be seen, however, whether these individual factors will show their effects in the same way within a collective context. Positional factors will, for example, influence the importance of individual interactive skills: e.g. leadership or supervisory positions in the collective, or for individual skills affecting tasks on the critical path for the collective task.

The factors identified will interact in complex ways. For example, the interaction between individual aptitude and the level of task intersection will have implications for predicted retention. For collectives in which individual aptitude is highly variable, for example, a high level of serial task intersection (that is, sub-tasks must be completed sequentially) may be particularly problematic. As such, it is important to consider both the features of the task, and the features of the individuals within a collective. Similarly, it is also critical to consider the entire organizational context of a collective to understand and predict retention of collective performance.

An emerging area of great potential appears to be the concept of team mental models. If it is true, for example, that a superior team mental model is related to superior team performance, and that such cognitive structures for knowledge about team procedures , capabilities of other team members, interdependencies among sub-tasks, can be readily trained and maintained without actually undertaking training as an entire collective, this application would appear to have great potential not only for prediction of retention but as the basis for some forms of refresher training in the retention interval, and even for overcoming the effects of personnel turnover and turbulence.

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# 6. Models for Collective Skill Retention

The purpose of this section is to review existing models and approaches relevant to the issue of predicting collective skill retention. Our search yielded only one model directly relevant to this problem, but two other approaches that, although not specifically designed to address the issue of collective skill retention, either contribute important factors to this purpose or may be adaptable to predicting collective skill retention.[4]

In this section, we describe these models (or approaches), explore how each was developed, and evaluate the extent to which each of these approaches may contribute to the prediction of collective skills. The evaluation considers the types of skills to which the model is potentially applicable, the empirical support for the validity of the model, the information needed to use the model, and the practical issues associated with its use (e.g. time, cost). Lastly, each model will also be evaluated against the categorisation framework.

The section covers the following topics:

- Nichol's approach
- The ARI model
- Roth's model
- Comparison of these models to the categorisation framework

## 6.1 Nichol's Approach to Predicting Skill Retention

Nichol (Nichol, unknown date reported in Spears, 1991b) presents a simple and easy to use approach to predicting skill retention for both individual and collective military tasks. Although our insight into this model is limited to the brief description provided in a secondary reference, it is included in the review as an important example of an attempt to predict the need for refresher training within a military context. Spears interest was in air force ground defence tasks. Although the detail provided is limited, these appear to be primarily individual tasks classified as not difficult or of moderate difficulty, such as first aid or donning a gas mask. Some tasks, such as fire fighting, imply team work but no details are given.

### 6.1.1 Theoretical Bases

This approach can be described as atheoretical as its focus is mainly pragmatic. Its goal is to estimate training and refresher training priorities and frequencies within a military context, based on task difficulty, importance, and normal frequency of performance. Although the development of Nichol's model is unknown, Spears (1991b) indicates that the model was based on the ARI model. Both Spears and Nichol's work appear to address both training and refresher training, but we limit our discussion primarily to the prediction of the need for refresher training.

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[4] We recognize that the Nichol's approach is not a model, in the sense that it uses a practical approach, rather than being theoretically grounded. Nonetheless, we have included it within the "model" chapter as a way of representing the range of approaches used to understand collective skill retention.

### 6.1.2 Using Nichol's Approach

To estimate how often tasks need refresher training, tasks are rated for difficulty, importance and frequency of performance. Nichol defines each dimension and describes task features for different levels.

*Task difficulty*, for example, is defined as the amount of training needed for the task to be acquired, and the amount of part-task training needed for successful first performance of the task, with tasks being rated as easy, moderately difficult or very difficult. To help identify task factors, a descriptor of task difficulty is provided for each level of difficulty. This descriptor highlights factors seen in the existing research (e.g. Rose et al., 1985b) to contribute to individual skill retention, such as the number of steps in the task. For example, very difficult tasks are described as follows:

> *Very Difficult - Very difficult tasks are complex tasks with a number of items or concepts that need to be considered at any one time. Several abstract rules need to be followed. There are many (more than 10) independent steps that need to be performed in order. There are several decision points with numerous branching. There is very close error tolerance requiring hand-eye coordination. There is no job aid.*

As can be seen, this task descriptor addresses the number of steps in the task and a job aid (ranging from a "memory jogger" to "all information necessary"). Raters are asked to consider the task in question against the task descriptor, and to rate the difficulty of the task by choosing the descriptor which matches best the task in question.

*Task importance* is defined in terms of the consequence of inadequate or improper performance on the job. Descriptors of importance are also provided as examples. For example, the description of a low importance task is as follows:

> *Low Importance – If the task is not done, or is done incorrectly, it may create hardship or discomfort, but will not cause injury or greatly impair successful performance*

*Task frequency* ratings are based on the premise that tasks that are performed more infrequently will be more affected by skill decay. (Spears, 1991a) comments that frequent but incorrect performance without corrective feedback will have a negative effect and affect not only with future performance, but require unlearning and corrective training.) Task frequency ratings address whether a task is performed very often (at least once every two weeks), moderately frequently (at least once every eight weeks), or not frequently (not done for more than 8 weeks).

*DIF ratings* (Difficulty, Importance and Frequency) are completed by experts familiar with the task. A matrix with 27 possible outcomes is then used to convert DIF values into a recommendation for training priorities. Each matrix combination is associated with a training priority value, ranging from 1 to 6. Higher ratings indicate a higher priority for and a different choice of six types of refresher training.

| Task Difficulty | High (H) | | | | | | | | | Moderate (M) | | | | | | | | | Low (L) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Task Importanc | High | | | Mod | | | Low | | | High | | | Mod | | | Low | | | High | | | Mod | | | Low | | |
| Performance Frequenc | H | M | L | H | M | L | H | M | L | H | M | L | H | M | L | H | M | L | H | M | L | H | M | L | H | M | L |
| Type of training needs | 2 | 1 | 1 | 2 | 2 | 1 | 3 | 3 | 2 | 3 | 2 | 2 | 3 | 2 | 2 | 4 | 3 | 5 | 4 | 4 | 3 | 4 | 4 | 3 | 5 | 6 | 6 |

**Table 5: Training Priority Based on Task Difficulty, Importance and Frequency** (adapted from Nichol, in Spears, 1991b)

Nichol's approach also provides an aid, used to match the training priority with a training approach. This aid provides a description of the training needs, and lists the characteristics of tasks with which it is appropriate to employ the training approach.

| Training Priority | Training Approach | Description of Training Needed | Tasks Appropriate for this Approach |
|---|---|---|---|
| 1 | Comprehensive | A series of 3-5 training sessions with correct performance achieved in each training session and job proficiency attained by the last session. | Very difficult tasks of moderate to high importance, tasks performed infrequently or required correct performance on the job without time to practice |
| 2 | Progress –ive | A series of 3 training sessions with correct performance, including job proficiency by the last training session. | Tasks performed infrequently, but not as critical or difficult as priority 1 tasks, or moderately difficult tasks that must be performed correctly on the job without time to practice. |
| 3 | Double Session | Two separate training sessions with correct performance achieved in each. Job proficiency is attained on the job. | Tasks moderately or very difficult and important, and performed on the job at least moderately frequently. The tasks must be learned in training, but may be mastered on the job. |
| 4 | Single Session | A single training session with the task performed at least on time correctly. Job proficiency is attained on the job. | Tasks moderate or less in difficulty and importance and performed frequently on the job. Tasks are learned in training but may be mastered on the job. |
| 5 | Explain & Demonstrate | Tasks deserve or require explanation, but actual performance is left for on the job. | Very easy tasks of limited importance except perhaps, as they relate to other tasks. They are performed on a moderate to frequent basis on the job and may be learned on the job. |
| 6 | On the Job | Training is accomplished on the job on an as needed basis. | Very easy tasks of limited importance performed on an infrequent basis on the job. |

**Table 6: Description of Training Approaches (in Spears, 1991b).**

Lastly, the Nichol's model also provides general guidelines for retention intervals for tasks with varying levels of difficulty in accordance with several training strategies, listed in the table below.

Unfortunately, no information is provided as to how these values were derived and it is unclear whether they are empirically based, or estimates of predicted skill retention over time. In terms of table interpretation, the values for a given task and week represent the predicted average performance of the specific task. This table can be used to predict either the probable performance on a given task after a specified number of weeks have elapsed, or to predict the need for refresher training, given a specific proficiency target.

| Training Strategy | Task Difficulty | Weeks since last performance | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| Single session | very | 94 | 89 | 84 | 79 | 75 | 71 | 67 | 63 | 60 | 56 | 53 | 50 | 47 |
| | moderate | 99 | 97 | 96 | 95 | 93 | 92 | 91 | 89 | 88 | 87 | 86 | 85 | 83 |
| | not | 99 | 99 | 98 | 97 | 97 | 96 | 95 | 95 | 94 | 94 | 93 | 92 | 92 |
| Double session | very | 96 | 93 | 89 | 86 | 83 | 79 | 76 | 74 | 71 | 68 | 66 | 63 | 61 |
| | moderate | 99 | 99 | 98 | 97 | 97 | 96 | 95 | 95 | 94 | 93 | 93 | 92 | 91 |
| | not | 100 | 99 | 99 | 99 | 99 | 98 | 98 | 98 | 98 | 97 | 97 | 97 | 96 |
| Pro -gressive | very | 97 | 94 | 92 | 89 | 87 | 84 | 82 | 79 | 77 | 75 | 73 | 71 | 69 |
| | moderate | 99 | 99 | 98 | 97 | 97 | 96 | 95 | 95 | 94 | 93 | 93 | 92 | 91 |
| | not | 100 | 99 | 99 | 99 | 98 | 98 | 98 | 97 | 97 | 97 | 96 | 96 | 96 |
| Compre -hensive | very | 98 | 95 | 93 | 91 | 89 | 87 | 85 | 83 | 81 | 79 | 77 | 75 | 73 |
| | moderate | 99 | 99 | 98 | 98 | 97 | 97 | 96 | 95 | 95 | 94 | 94 | 93 | 93 |
| | not | 100 | 99 | 99 | 99 | 99 | 98 | 98 | 98 | 98 | 97 | 97 | 97 | 96 |

| Training Strategy | Task Difficulty | Weeks since last performance | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
| Single session | very | 45 | 42 | 40 | 38 | 36 | 34 | 32 | 30 | 28 | 27 | 25 | 24 | 22 |
| | moderate | 82 | 81 | 80 | 79 | 78 | 77 | 76 | 75 | 74 | 73 | 72 | 71 | 70 |
| | not | 91 | 90 | 90 | 89 | 89 | 88 | 88 | 87 | 86 | 86 | 85 | 85 | 84 |
| Double session | very | 58 | 56 | 54 | 52 | 50 | 48 | 46 | 45 | 43 | 41 | 40 | 38 | 37 |
| | moderate | 88 | 87 | 86 | 85 | 85 | 84 | 83 | 82 | 82 | 81 | 80 | 79 | 79 |
| | not | 94 | 94 | 93 | 93 | 92 | 92 | 91 | 91 | 91 | 90 | 90 | 89 | 89 |
| Pro -gressive | very | 67 | 65 | 63 | 61 | 60 | 58 | 56 | 55 | 53 | 52 | 50 | 49 | 47 |
| | moderate | 91 | 90 | 89 | 89 | 88 | 88 | 87 | 86 | 86 | 85 | 85 | 84 | 83 |
| | not | 95 | 95 | 95 | 94 | 94 | 94 | 94 | 93 | 93 | 93 | 92 | 92 | 92 |
| Compre -hensive | very | 72 | 70 | 68 | 67 | 65 | 63 | 62 | 60 | 59 | 58 | 56 | 55 | 54 |
| | moderate | 92 | 92 | 91 | 91 | 90 | 90 | 89 | 89 | 88 | 88 | 87 | 87 | 86 |
| | not | 96 | 96 | 96 | 95 | 95 | 95 | 95 | 94 | 94 | 94 | 94 | 93 | 93 |

**Table 7: Predicted Skill Retention Over Time (in Spears, 1991b).**

### 6.1.3 Applicability and Practicality

There is little evidence from the available literature related to how this model has been used to predict skill retention. Spears (1991b) does use this model to estimate the proficiency on ground defense tasks (Table 8) for up to one year after training. An important implication of the Spears review is that prediction of retention needs to be considered together with the type of training to be provided. Spears describes six training approaches ranging from on the job feedback to systematic multi-session training. Spears advocates individual testing prior to commencement of any form of training to confirm that performance is indeed incorrect before continuing with any training. The assumption is made that the tasks of interest will continue to be performed over the period in question to some degree, resulting in consideration of performance frequency as a factor.

| GDT Tasks | Task components | Task Difficulty |
|---|---|---|
| Weapon skills | Weapon handling | Moderately difficult |
| | Rules of engagement | Very difficult |
| | Field craft | Not difficult |
| First Aid | | Not difficult |
| NBC | Warnings | Not difficult |
| | Personal Drills | Moderately difficult |
| | Shelter Drills | Not difficult |
| Post attack recovery | Reporting | Moderately difficult |
| | Searching | Moderately difficult |
| | Firefighting | Moderately difficult |
| | IEDs/UXB | Moderately difficult |

**Table 8: Ground Defence Tasks (GDT) (Spears, 1991b)**

These tasks were then used to rate the common core GDT tasks and their components. As the Nichol's retention table only extends to 14 weeks, b (1991) extended the prediction tables to weeks 28 to 52, assuming a linear decline in performance. Note that Spears (1991b) appears to include both individual and collective tasks with no distinction between them. This suggests that it is theoretically possible to use the Nichol's approach with all kinds of tasks. Unfortunately, Spears (1991b) provides no additional detail about how the estimates derived from Nichol's approach were used, but presumably they were used to predict task proficiency after intervals without training. Spears recommends medium (four month) and longer term validation studies to evaluate the Nichol's model, but references to such work were not found. As a whole, then, there appears to be very little work available on the validity of the Nichol's approach to predict the retention of skill, collective or otherwise.

Nonetheless, this approach represents a simple and very low cost, paper and pencil measure that requires little training to administer. Nichol's approach is sufficiently broad that it can be used with virtually any task that can be specified. As the success of this model is predicated on the ability to segment tasks, it remains to be seen how easily more complex collective tasks (e.g. command and control tasks) could be dealt with.

Despite its ease of use and its wide range of applicability, however, it seems unlikely that such an approach, on its own, has the sophistication needed to predict collective skill retention. Identifying task difficulty as an important predictor of skill retention, of course, is not a unique contribution of this model, but other conceptualisations of task difficulty or complexity (the UDA model, for example) allow less room for misinterpretation by raters. Moreover, although it seems clear that task difficulty, importance and frequency may well play a role in collective skill retention, it seems unlikely that they are the most important predictors of collective skill loss, or that their description as sub-tasks in relation to the overall collective tasks cannot be improved. Most importantly, the Nichol's approach overlooks the nature of the collective, the training environment, and many other characteristics of collective tasks that are likely to impact on skill retention. It is possible that modification of Nichol's evaluation scales to include collective aspects, such as task interdependence, might permit extension to collectives and their tasks – but this is doubtful.

Perhaps Nichol's most important contribution is to specify the importance of the task, in terms of the real life consequences if the task is not completed properly. This factor seems a critical one within military contexts with limited resources, and consideration of the importance of the task should be incorporated into ratings of collective refresher training priority. Considering the frequency with

which the task is normally performed is also somewhat unique and underscores the difficulty of defining the retention interval as being a period during which no practice whatsoever occurs.

In conclusion, although this model does not seem complex enough to warrant further advancement, task importance and frequency are concepts to consider for future models of collective skill retention, but with better measures of each of these dimensions.

## 6.2 The ARI Model of Skill Retention[5]

The most fully developed model designed to predict skill retention at the individual level is the User's Decision Aid (UDA), developed by the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) (Rose et al., 1985a; Rose et al., 1985b). This model was developed specifically to provide quantitative predictions of skill retention for individual military tasks.

Although the UDA model, as originally conceived, focused mainly on procedural skills, rather than on the broader range of continuous and even cognitive skills, subsequent research has worked to extend the range of individual skills predicted. Because of the prominence of this model within the skill retention literature, its ease of use, and its promise, this research is reviewed in the following sections, with a view toward explored the possibilities of extending the model further, to collective skill retention.

### 6.2.1 Theoretical Bases

The UDA model is based on years of research conducted by the ARI. As researchers uncovered the personal, task, training, and job condition factors that affect skill retention, they began to work on descriptive procedures to identify more precisely how these factors produced deterioration of skills (e.g., Hurlock & Montague, 1982). The ARI established their modelling effort to develop and validate a convenient, practical method for unit commanders and training managers to decide upon the allocation of training resources to maximize combat readiness (Rose et al., 1985b).

The first issue dealt with in the ARI initiative was deciding which factors were relevant to prediction of individual skill loss as well as feasible for use in prediction. Since testing large number of soldiers on each Army task to derive empirical individual retention curves would be extremely resource intensive, the ARI instead used the factors already identified in the research literature to develop theoretical retention curves for use in prediction of skill loss (Rose et al., 1985b).

Several ARI projects had investigated a broad range of factors that impact on the ability of individuals to retain previously acquired skills over extended periods of time. This program of research explored the effects of various training variables, such as overlearning (Hagman & Rose, 1983), and practice schedules (Schendel & Hagman, 1982). In addition, the program explored the effects of individual abilities on the retention of skills, and concluded that the effects of individual ability measures were inconsistent (Rose et al., 1985b). These ARI studies also identified a number of task characteristics affecting skill retention such as task difficulty, the number of steps required to complete the task, interstep cueing, and step relevance (Rose et al., 1985b).

As the result of this work, ARI researchers decided that factors related to training and individual differences presented unacceptable, practical problems of assessment, and chose to focus on task factors as predictors of skill retention. Work by Wisher et al. (1999) reviews the major task factors identified

[5] This section is taken and adapted from Bryant and Angel (2000).

and used in the ARI model, summarized in the table below: These task factors were the starting point for development of the UDA model.

| Task Factors Identified by the ARI | |
|---|---|
| 1. | Number of steps |
| 2. | Whether steps must be performed in a set sequence |
| 3. | Whether the task contains feedback that indicates the correct order of steps |
| 4. | Number of facts or information chunks that must be recalled |
| 5. | Execution demands |
| 6. | Whether the skill is cognitive or perceptual/motor |
| 7. | Whether there are job and/or memory aids for the task |
| 8. | The time limit of the task (if any) |

**Table 9: Task Factors Identified During Development of the UDA Model of Skill Retention**

### 6.2.2 Development of the Model

The ARI model of skill retention was designed to address the issue of how rapidly individual tasks, once learned, are forgotten over intervals without practice. The major goal of the ARI project was to determine a way to keep soldiers proficient in tasks (Rose et al., 1985a). Given that forgetting will occur, the ARI model concentrated on developing a tool to increase the efficiency of scheduling refresher training. This tool would enable accurate prediction of which tasks are likely to drop below a criterion level of performance, so that only necessary refresher training could be scheduled. The measure used by the UDA model was the percentage of soldiers in the study who were at or above the criterion performance level and the percentage of task steps for which soldiers were at or above criterion performance.

The UDA was developed according to a few basic steps (Rose et al., 1985b):

1. Identify task dimensions most likely to be related to retention.
2. Convert task dimensions into rating scales, develop anchor points, and analytically assign weights to each point on the scales.
3. Assess each scale's reliability and validity by having several judges rate tasks on each scale.
4. Examine inter-rater agreement and correlation between task ratings and actual retention data.
5. Iterate these steps to develop a set of valid and reliable scales.

Rose et al. (1985b) describe each of these steps in detail, effectively laying out a "cookbook" for development of a model of skill retention. The remainder of this section will briefly describe the methodology.

The basis of the UDA model is the algorithm that weights and summarizes the relevant task factors (Table 9 above) to produce a single task retention score. This score is then used to predict soldiers' level of task proficiency over time. ARI researchers developed the initial algorithm from the empirical literature available. To refine the algorithm, researchers then performed regression analyses on data obtained from previous ARI studies. The regression equations obtained for the set of eight task variables indicated substantial correlations between retention at two months among the factors. Correlations between retention at four months and the factors were not as high but still significant. Thus, the initial algorithm was deemed to provide a viable means to predict skill retention.

To refine the algorithm further, ARI researchers collected performance data from soldiers for a sample of 13B10 (cannon crewman) tasks, according to the Military Occupational Speciality (MOS) definitions. These data were used to establish empirical acquisition and retention functions (performance plotted as a function of time) and to examine the relationships of task factors to retention. The MOS tasks used in this phase of the project were all basic skills. A total of 11 tasks could be tested within the constraints of the study.

Based on these early studies, researchers were able to develop and implement the UDA procedure and to determine values for each rating option of the UDA questions. This research also improved the comprehensibility of the rating procedure based on user feedback. The ARI researchers had to create the preliminary model using arbitrary assumptions rather than deriving scale values empirically. Furthermore, the relative weights for rating scales and the rule for combining them were also arbitrary. The researchers did this because they had not had access to a sufficient pool of tasks to conduct regression analyses necessary to determine best-fit values.

To increase the number of cases, researchers combined data sets from multiple former studies to create a data set containing data on a total of 54 tasks. To decrease the number of task characteristic predictors, they performed a factor analysis of the task dimensions comprising the UDA, which reduced the number of independent predictors to five. Eight raters then made ratings for the 54 tasks. From the data set, the researchers determined the percentage of soldiers in the study who were at or above the criterion performance level (i.e. GO) and the percentage of task steps for which soldiers were at or above criterion performance (i.e. GO[6]). Analyses resulted in empirically-based scale values for the answer options within each UDA rating question. This scaling procedure is critical to convert the retention level predicted in the model into a value for "real-world" retention. It also provided regression weights for each UDA question to account for differences in the importance of different factors.

We can break down this procedure into five more specific steps.

**The first step** involved creating a matrix of the raters' modal responses arrayed by eight UDA factor questions (Table 9 above) and the 54 tasks. Then, researchers input the mode matrix into an analysis of variance (ANOVA) and conducted separate ANOVAs for each of the eight UDA questions, with percent soldiers GO as the dependent variable and answer options for each question as the independent variables. They then generated cell means for each answer option of five of the eight questions. The remaining three questions had non-significant F values and so weights were assigned arbitrarily.

**In the second step**, researchers then transformed the matrix of modal responses by replacing each entry with the corresponding cell mean from the ANOVA. Thus, the matrix values corresponded to the mean percentage of soldiers GO for all tasks with a given question option. For example, this would change a rating of "2" in the question pertaining to the presence of job aids to "61.3," which was the mean percent of soldiers GO for all tasks with "Good" job aids. The factor analysis indicated that four questions which could be interpreted as the cognitive demands of the task loaded significantly onto one factor. Thus, researchers combined these questions into a single independent variable by adding values, reducing the original eight factors or questions to five variables of interest.

**The third step** was to multiply matrix values by the question weights. The regression analysis examined the relationship between five UDA variables and mean two-month retention performance

[6] The term GO indicates that personnel are capable of performing a task successfully.

across the 54 tasks. The results indicated that the five predictor variables accounted for 79% of the variance in performance.

**The fourth step** involved transforming the scale values. The weights were rounded off to the nearest whole number and a constant added or subtracted for each UDA question so that the lowest value equalled zero. The sum of the additions and subtractions were added to the regression equation constant so that the transformations had no effect on the regressions but improved the usability of the scales.

**The final step** was to add up the eight transformed scores for each task to arrive at a total UDA score for each task.

The purpose of the UDA model is to generate numerical predictions of skill retention. Thus, an important issue is how to relate predictions of the model to actual performance; in other words, what does a UDA value of, say, 86 mean and how can it be used to estimate performance (Rose et al., 1985b)?

The translation of UDA value for predicting two-month retention performance is straightforward. Because the option weights and combination rule were developed from data on two-month retention performance; a UDA value of 86 is a prediction of 86% of 40 (the constant in the regression equation) or 26% proficiency after two months. In other words, 26% of soldiers in a unit will be able perform the task to the required criterion two months after receiving training in a given skill.

ARI researchers also developed a best fit generative function to allow prediction at any retention interval. The best fitting function was:

$$p = 100 * (UDA/100)^{1/8}$$

where p is the predicted proficiency and y is the retention interval in weeks.

Thus, retention performance after y weeks of no practice is predicted by dividing the UDA value (after subtracting the constant i.e. 40) by 100, taking the eighth root, raising the result to the yth power (i.e. the number of weeks without practice), then multiplying by 100. At two months, y = 8, and the formula reduces to just the UDA score. Researchers then turned to improving the usability of the UDA. Actual and potential users of the model were interviewed. Based on this feedback, researchers revised the questions and instructions to improve comprehensibility and convenience of the UDA as a tool for predicting skill retention.

### 6.2.3 The UDA Decision Aid

The UDA model was developed to form a decision aid tool to be used in predicting skill retention and the need for refresher training in military tasks (Rose et al., 1985a). Specifically, the UDA is used to determine (Rose et al., 1985a; Wisher et al., 1999):

- How quickly task skills will be forgotten.
- Which task among several will be forgotten or remembered after a specified interval.
- What percent of soldiers will be able to perform a task after up to one year without practice.
- When to conduct refresher training to keep a group at a criterion level.

The UDA employs ratings of task characteristics to predict skill retention. The ratings are made by individuals with extensive knowledge of the task. Optimally, more than one person performs task ratings

to ensure accuracy (Rose et al., 1985a). Differences in ratings must be resolved by discussion because the UDA accepts only a single value for each rating. All that is required to make task ratings is a task summary that provides descriptive information that can help resolves differences of judgment and reduce the subjectivity of ratings (Rose et al., 1985a). If no task summary is available, having raters write their own summary can help them be more thorough and objective.

| Question | Scale Values | Factor |
|---|---|---|
| 1. Are job or memory aids used by the soldier in performing (and in the performance evaluation of) this tasks? | 1 (yes), 0 (no) | Task Characteristic; Presence of job aid |
| 2. How would you rate the quality of the job or memory aid? | 56 (excellent), 25 (very good), 2 (marginally good), 1 (poor) | Task Characteristic; Presence of job aid |
| 3. Into how many steps has task been divided? | 25 (one), 14 (two to five), 12 (six to ten), 0 (more than ten) | Task Characteristic; Number of steps |
| 4. Are the steps in the task required to be performed in a definite sequence? | 10 (None), 5 (all), 0 (some are and some are not) | Task Characteristic; Organization |
| 5. Does task provide built-in feedback so that you can tell if you are doing each step correctly? | 22 (for all steps), 19 (for greater than 50% of steps), 11 (for up to 50% of steps), 0 (for none) | Task Characteristic; availability of feedback |
| 6. Does the task or part of the task have a time limit for its completion? | 40 (no time limit), 35 (easy time limit), 0 (difficult time limit) | Task Characteristic; Stress |
| 7. How difficult are the mental processing requirements of this task? | 37 (almost no requirements), 28 (simple requirements), 3 (complex requirements), 0 (very complex requirements) | Task Characteristic; Difficulty |
| 8. How many facts, terms, names, rules, or ideas must a soldier memorize to do task? | 20 (none), 18 (one to three), 13 (four to eight), 0 (more than eight) | Task Characteristic; Difficulty |
| 9. How hard are the facts, terms, that must be remembered? | 34 (not applicable; none to remember), 31 (not hard at all), 12 (somewhat hard), 0 (very hard) | Task Characteristic; Difficulty |
| 10. What are motor control demands of task? | 2 (none), 0 (small), 16 (considerable), 3 (very large) | Task Characteristic; Difficulty |

**Table 10: UDA Questions and Scale Values formatting**

The UDA contains ten questions that raters answer based on the task summary and their knowledge of the task. Each question has a set of answers to choose from. Raters select the appropriate answer and note the scale value associated with the selected answer. The questions and their scale values are listed in Table 10. When all ten questions have been answered, the raters compute the total of the scale values, which constitutes the task's retention score. Multiple raters review the ratings given to the task and resolve differences to produce a final, agreed-upon task retention score.

The UDA contains two Performance Prediction Tables that are used to convert the total retention score into a prediction of performance for the rated task. The numbers in the tables represent the expected *proportion of soldiers in a unit* that are able to perform the task correctly at various retention intervals up to one year without practice. The UDA does not predict retention performance for individuals. The first table plots the expected proportion of soldiers versus monthly intervals, whereas the second table plots the expected proportion of soldiers versus weekly intervals.

| | Predicted % of Soldiers at Criterion Performance Level | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Months Since Last Performance | | | | | | | |
| Total Score | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 180+ | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 175 | 97 | 95 | 92 | 90 | 87 | 85 | 83 | 81 |
| 170 | 94 | 90 | 85 | 81 | 76 | 72 | 69 | 65 |
| 165 | 92 | 85 | 78 | 72 | 66 | 61 | 56 | 52 |
| 160 | 89 | 80 | 71 | 64 | 57 | 51 | 45 | 40 |
| 155 | 86 | 75 | 64 | 56 | 48 | 42 | 36 | 31 |
| 150 | 83 | 70 | 58 | 49 | 40 | 34 | 28 | 24 |
| 145 | 80 | 65 | 52 | 42 | 34 | 27 | 22 | 17 |
| 140 | 77 | 60 | 46 | 36 | 27 | 21 | 16 | 12 |
| 135 | 74 | 55 | 40 | 30 | 22 | 16 | 12 | 9 |
| 130 | 70 | 50 | 35 | 25 | 17 | 12 | 8 | 6 |
| 125 | 67 | 45 | 30 | 20 | 13 | 9 | 6 | 4 |
| 120 | 63 | 40 | 25 | 16 | 10 | 6 | 4 | |
| 115 | 59 | 35 | 20 | 12 | 7 | 4 | | |
| 110 | 54 | 29 | 16 | 8 | 4 | | | |
| 105 | 50 | 25 | 12 | 6 | | | | |
| 100 | 44 | 20 | 8 | | | | | |
| 95 | 38 | 15 | | | | | | |
| 90 | 31 | | | | | | | |

**Table 11: UDA Performance Prediction Table (Month Intervals)**

To find the percentage of soldiers expected to be able to perform the rated task, raters find the table entry corresponding to the total retention score and the retention interval of interest.

- To determine how frequently refresher training is needed, raters find the row corresponding to the total retention score then locate the table entry of 50% (or any other criterion). The retention interval at which the criterion occurs is the maximum interval for refresher training to sustain a unit at the criterion level.
- The level of proficiency expected for a unit that receives refresher training at a given interval of time (e.g., every X months) is given by the table entry corresponding to the total retention score and the interval (X months).

### 6.2.4 Empirical Evaluation

Many studies cited in support of the UDA (such as Macpherson et al., 1989; Sabol et al., 1990; Wisher et al., 1991) did not actually compare predicted retention performance to actual retention performance. As such, they do not provide a true validation of the UDA because the accuracy with which the UDA predicts skill retention cannot be determined.

Only one study was found to report a comparison between UDA predictions and actual retention data. Rose et al. (1985b) used data collected from a sample of 22 13B10 (cannon crewman) MOS tasks that had not been used in the development of the UDA to compare predictions of the UDA to actual skill loss. Each of these 22 tasks was rated by 5 task experts on the 10 UDA task dimensions. Inter-rater correlation on the task ratings was quite high, with an average correlation of more than 0.9, suggesting good agreement on the task ratings for the 22 tasks. Soldiers were trained to 100% proficiency on the

tasks, and performance measures were taken at intervals of 2, 5 and 7 months. In terms of the percentage of soldiers "GO", the correlation between the actual performance and the predicted performance was significant at all 3 intervals, with the best correlation (r = .90) at the 2 month interval. At the 5 and 7 month intervals, there was an increasing tendency toward underestimating the prediction scores. Similarly, in terms of the number of steps "GO" for each task, the correlation between actual and predicted performance at all 3 time intervals was also significant, ranging from .83 at 2 months to .70 at 7 months. This work is the only available empirical evaluation of the UDA model, but it does provide evidence that the UDA model can predict the retention of individual skills. No research was found that used the UDA model to predict retention of collective tasks.

### 6.2.5 Applicability and Practicality

There is good evidence for the applicability and practicality of the UDA procedure for predicting individual task retention, as it has been used fairly extensively for predicting the retention of individual skills. The UDA model has been used to predict skill retention on several vehicle maintenance tasks (Macpherson et al., 1989) and has shown itself to be relatively easy to use. Instructors' task ratings were completed in only about 12 minutes per task, with instructors showing little difficulty in reaching agreement on task ratings. Moreover, theoretical retention curves were also completed for several of these tasks, which allowed the prediction of the task characteristics most likely to impact on skill decay within this set of vehicle maintenance tasks. This work, although theoretical, speaks to the ease with which the UDA approach can be used to understand skill retention within a given task domain.

Predictions of retention using "peace support operation" tasks (Wisher et al., 1996) have also been formed using the UDA model. As in the Sabol et al. (1990) study, SMEs rated a number of tasks and these ratings served as a basis for computing skill retention curves using the UDA. Although no comparison to actual retention performance was made, the UDA predictions were sufficiently precise to allow researchers to rank order tasks in terms of their expected difficulty and susceptibility to forgetting. This rank order was distributed in a guide job aid to Army trainers for Operation Joint Endeavor in Bosnia.

These studies demonstrate that it is feasible to use the UDA to differentiate and prioritize individual tasks within a specific domain. Raters were able to identify those tasks most susceptible to skill decay and make predictions of when refresher training would be needed. Both studies also demonstrate the practicality of the UDA. The use of the UDA is a cost-effective supplement to field studies that requires few materials and relatively little effort. In addition, the resolution procedure of the UDA seems to work well and allows multiple raters to achieve a single retention score. The UDA has been demonstrated to be relatively easy to administer. Some training is needed to perform the ratings correctly and reliably but this training requirement does not seem to be excessively burdensome (Radtke & Shettel, 1985). As a paper and pencil measure, the UDA itself is low-cost and requires no special equipment.

Despite its apparent applicability, however, the UDA model as originally conceived has a number of potential limitations in addressing collective and cognitive skill retention. The most obvious limitation is that it was originally designed for tasks which are highly procedural, as opposed to primarily cognitive or continuous motor tasks (Sabol and Wisher, 2001). As most collective tasks are comprised of both cognitive and continuous motor tasks, the original UDA's ability in this respect may be somewhat limited.

More recent work, however, has extended the UDA model's range of applicability to a broader set of skills. Although this work addresses the measurement of only some cognitive skills, it represents a

significant step forward in terms of thinking about how to model collective skill retention. Two studies have attempted to address more cognitive skills, and have used the UDA model in an unaltered and considerably altered form.

The first effort to model more complex and cognitive skills used the UDA model without alterations. Work by Sabol et al. (1990), for example, has extended the ARI model to tasks associated with mobile subscriber equipment operator skills. These researchers used the UDA model to make predictions of the decay functions for 85 skills needed to operate a communication system called Mobile Subscriber Equipment (MSE). MSE is a radio telephone system and its operation was considered to entail many complex, highly cognitive skills within MOS 31D (MSE Network Transmission Operator) and MOS 31F (MSE Network Switch Operator).

Sabol et al. (1990) had six SMEs serve as raters. Three of the SMEs were experts on MOS 31D procedures and three on MOS 31F procedures. Using task inventories generated during the development of the MSE's Soldier's Manuals and lists of skills generated during field evaluation of MSE, the raters completed the ten question rating procedure of the UDA for all 85 tasks. Each SME was interviewed separately and took about two hours for MOS 31D tasks and about three hours for MOS 31F tasks.

The purpose of their study was to predict retention of MSE operator skills and to expand the UDA to cover more complex skills than those examined in its development. Sabol et al. (1990) reported that they intended to obtain data with which to compare predictions of the percentage of soldiers GO for each task to actual performance data of MSE operators. However, we were unable to identify any publication reporting the results of such a comparison. Although this work only creates predicted (rather than actual) retention curves, it stands as one effort to broaden the UDA model's scope beyond highly procedural tasks.

More recent work by Sabol and MacPherson (2000)[7] attempts an even wider adaptation of the UDA skill retention model to "*digital*" tasks. Digital tasks, as defined by Sabol and MacPherson, are tasks performed on a computer such as surveillance tasks involving situational awareness and requiring communication, interpreting information, problem solving, and making decisions. Sabol and MacPherson (2000) argue that as the UDA model is based on mainly procedural tasks, it may be necessary to recalibrate the model for predicting the retention of computer-based military tasks. If the UDA is seen to be an inadequate predictor, then the model will need to be extended to include a broader range of skills. This work appears to be a first step toward these goals. Two digital tasks are explored in this work, including an intelligence gathering task (MOS 96B) and a task related to field artillery tactical data systems (MOS 31D).

This work began with conducting interviews with SMEs about these 2 tasks, and having the SMEs generate predictions of the vulnerability of the task and associated sub-tasks to decay. These predictions were based on an enhanced system of measurement, which incorporated new dimensions (see below) likely to impact on the retention of tasks performed on a computer. In addition to the original 10 UDA questions, additional questions related to the cognitive components of the task. The digital task retention activity matrix included the following items, rated on a 5-point scale, ranging from the extent to which the activity was "crucially involved" or "not at all involved" in the performance of the task. These activities included:

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[7] This description is based on a short Power Point presentation.

- Following a fixed procedure
- Executing a continuous perceptual-motor action
- Monitoring a situation or system
- Adjusting or manipulating equipment
- Communicating information
- Receiving, combining, interpreting information
- Making decisions
- Solving problems, trouble-shooting

The following illustrates digital task retention questions completed by instructors:

- Extent to which situation awareness is a factor in the completion of the task
- How difficult it is to maintain situation awareness while performing the task
- How often a given task is practiced during training
- A self-assessment of retention completed by soldiers
- Whether the task can be performed in more than one way
- Whether all soldiers are required to learn all versions of the task before receiving a "GO"
- Whether the equipment used has capabilities beyond those needed for the task
- Whether the soldier benefits from being familiar with other capabilities of the equipment.

These scores were combined into a task complexity/cognitive component score for each task. SMEs also rated these tasks by how likely each of the tasks and sub-tasks were to decay over time.

SME ratings of the decay associated with each task were regressed on both the original 10 UDA task questions, and with the expanded cognitive and digital measures, with varying results. In the first trial, the original 10 UDA questions predicted the SME ratings of the task fairly well, and there little added benefit was found from the additional "digital" and "cognitive" questions. In the second trial, the digital questions predicted skill retention better than the original UDA questions. Moreover, these tasks were rated by SME's to be highly vulnerable to decay. This preliminary report suggests that the inclusion of measures specifically geared toward tasks which are primarily cognitive may assist in the prediction of "digital" tasks, beyond what the original UDA on its own is able to achieve. However, the work needs to be examined in greater detail and the nature of the surveillance in the tasks better understood. There are some apparent contradictions, for example, in that skilled visual search tasks such as those involved in Air Traffic Control, depending on the manner of training, may have minimal declines in performance over periods as long as a year (Swezey and Llaneras, 1997, pp 530-1).

This work is potentially important to the prediction of collective skill retention from several perspectives. The issues rated in the digital skill retention activity matrix include the first attempt found to address operationally the cognitive component of tasks in the literature on prediction of skill retention. Furthermore, understanding tasks involving the communication of information and the need for decision making, for example, will be critical to predicting collective skill retention.

The existing literature (including the UDA model itself) argues that performing a task often provides feedback about the correctness of a task step, facilitating further responses. Spears (1991b) notes that failure to provide feedback to correct inappropriate performance will reinforce the incorrect procedure, and affect retention and re-training. Tasks without feedback are more susceptible to skill loss. For collective skill retention, an increasingly technological military system may help or hinder the

feedback process. Collective members need awareness of others to dovetail their activities. Digitisation may make this less effective (witness concerns about digitisation removing voice communication and the affective insight that can provide about other team members.) Digitisation may also help improve the situation through collation and display of information in ways that improve comprehension of the progress of the collective task.

Within collectives, the challenge is that any given collective member may have access to only one small part of the task, and may or may not know the outcome of collective task performance. As such, lessened situation awareness in both collective and increasingly cognitive settings may also impact on the long term retention of the related skills. Understanding the role of situation awareness will be important in future models of collective and cognitive skill retention.

One goal of this review is to consider the data needed to advance models that may be appropriate to apply to collective skill retention. We would argue that the recent work directed toward extending the scope of the UDA model to the cognitive domain is encouraging and necessary to enable prediction beyond simply procedural skills.

On the other hand, it could also be argued that even the original UDA model is still in need of strong empirical work even for prediction of relatively simple procedural tasks. Despite the promise of the UDA in predicting skill retention, validation studies comparing predicted retention with actual retention is still lacking. Work to validate the UDA model for procedural tasks may be more prudent than expanding the model for increasingly elaborate tasks, or in varying contexts. It is clear that creating predictions about the probable retention of tasks using the UDA models is possible. It is now important to show that these predictions are very closely related to the actual performance on these tasks, as measured by performance data. Also, the UDA approach as a whole seems to lack a strong conceptual and theoretical framework, and that adding piecemeal onto the existing approach contributes more to this atheoretical and somewhat scattershot nature of the model.

From a broader perspective, it is unclear whether a UDA model that continues to focus solely on task characteristics (however elaborated) will be adequate for modelling collective or cognitive skill retention. Indeed, one of the most common criticisms of the UDA model is that although its reliance on task factors makes the UDA very ease to use, the accuracy with which it predicts skill retention may be compromised because it overlooks many other important factors. These factors include:

- The degree of overlearning (Hagman & Rose, 1983; Lance et al., 1998; Schendel & Hagman, 1980, cited in Hagman & Rose, 1983).
- Opportunity to practice (Blankmeyer, 1998, Landry & Campbell, 1997)
- Similarity of training and performance environments (Marmie & Healy, 1995).
- Individual aptitude (Earles & Ree, 1992; Hurlock & Montague, 1982).

We would also argue that any model that excludes features of the collective (e.g. organizational structure, number of members within the unit etc), as well as training, and individual factors is unlikely to predict collective skill retention adequately.

On the other hand, using an approach like the UDA to understand collective skill retention may be an important starting point. Having identified the discrete tasks associated with the performance of a given collective skill, training subjects to asymptote performance, and measuring performance as a function of time would provide a decay curve for each task. With the decay curve for multiple tasks known, it would then be possible to explore the relationship between various task characteristics and the resulting curve for the collective task.

## 6.3 Roth Model of Collective Skill Training and Retention (1992)

Roth (1992) represents the only comprehensive attempt to model collective skill retention found during the literature search. This model was created to assist decision making by unit planners about collective training within U.S. Army units using data currently available from within the Standard Army Training System, and to predict how collective task performance would be affected by intervals without training, and by personnel turnover within the collective unit. Turnover data indicates annual turnover at the Battalion level as high as 60% to 120%. Based on analyses of battalion training schedules, inter-training interval (ITI) data indicates that most platoon collective tasks are practised as infrequently as twice a year.

Roth's work was very ambitious both in terms of the scope of the factors incorporated into the model and the range unit and tasks studied. The work was in four phases.

- The first phase sought to establish a conceptual model to organize the various factors seen to influence the retention of collective tasks and to understand how the factors impact on small military units such as infantry squads and platoons, with 30-60 Mission Essential Tasks. Choice of factors was based on the effect on the amount of information to be learned and remembered to accomplish the task. This phase also examined how differences in the structure and composition of military units might impact on predictions about collective skill retention.
- The second phase created regression equations to predict retention of proficient collective task performance over different periods without training with varying collective tasks and in varying kinds of units. Five SMEs (most with combat experience) provided estimates of likely performance of collectives under various conditions of time without training, and considering varying levels of turnover. Two hundred and thirty five collective tasks performed by 5 different types of units were used as a basis for these predictions. The predictions formed using the unit-type and the collective task categorisation schemes were then validated against the regression equations. To a lesser extent, predictions by SME's were compared against actual performance data to validate the categorisation.
- In the third phase, a conceptual model of the decision processes used by unit training planners to develop unit training was developed.
- In the final phase of work, user guidance was developed to support unit level planners of training including decision making strategies about when and how to provide collective training, and cost-effective training approaches.

### 6.3.1 Theoretical Bases

The first step in Roth's work was to define a conceptual model of the process of collective skill retention. In the absence of other existing frameworks for understanding collective skill retention, Roth used the team performance literature as a starting point. A model from the team performance literature created by Bass (1982) was adapted to model collective skill retention. Roth identified unique factors likely to influence collective skill performance after time without training and used a decision rule to assess how these factors would impact on skill retention within collectives. This decision rule for inclusion in the model was:

> *"Does the factor influence the amount that unit members must learn and remember in order to accomplish (a) collective task(s)?"*

This lead to the conceptual model, reproduced below:

Characteristics of a specific unit that influence skill and knowledge maxima (members' aptitude, overall experience, experience as a constituted team)
Unit design factors (threat, missions, echelon, etc.)
Potentially expressed skills and knowledge of unit members
Positions held by unit members in formal organizational structure of the unit
Unit type characteristics (number of members, equipment used, formal structure, positions and substitutability between them, leadership)
Characteristics of collective tasks performed by the unit type and lower echelons
Effects that limit the unit's ability to express maximum potential skills and knowledge (forgetting, membership change)
Collective task organization and process modifications
Individual tasks required to support collective task performance
Performance conditions and constraints
Individual task performance
Currently expressed capabilities (skills and knowledge) of unit members
Collective task performance

**Figure 7: A conceptual model of factors that influence collective task performance (Roth, 1992)**

The output of the model - collective task performance – is shown at the lower right of the model. As this complex model above shows, Roth argues that there are 3 broad classes or factors that influence collective performance within a collective, as a result of time without training and turnover. These include:

- **Unit Factors** - associated with the organization, structure, and tasks performed by types of teams or units (e.g. # of members, formal organizational structure).
- **Collective Task Factors** - associated with tasks performed by a specific type or unit (e.g. number of steps, ability to compensate for inadequate performance etc.)
- **Individual Factors** - associated with the characteristics of members of a specific team or unit (e.g. aptitude, job experience, experience in performing as a team).

Although Roth specifically excludes research on team mental models from the scope of this work, certain of the features of Roth's model overlap with the components proposed by research into team mental models.

Roth's model was seen to apply to less structured groups as well as with highly structured teams and able to be used with all of the tasks that collectives are likely to encounter including procedural, psychomotor and cognitive tasks. Each of these broad classes of factors can be further analysed in terms of several component factors (see below).

Defining Unit Types - In the early stages of work, Roth considered several different types of small military units, based on the assumption that the structure and composition of these units would uniquely influence the levels of skill retention within them. A unit was defined, in part, by the number of personnel within this unit, as well as by the composition of the unit, in terms of the proportion of unique roles (e.g. senior leader, junior leader, and non-leader) occupied by the members of the unit. However, it is not clear if the units studied were chosen to represent a full range of unit types with respect to the criteria of interest. In all, eight types of army units were considered:

- Armour Platoon
- Mechanized Infantry Platoon
- Light Infantry Platoon
- Light Infantry Squad
- Mechanized Infantry Squad
- Tank crews
- MLRS Firing Sections
- MLRS Firing Platoons

Diagrams showing the composition of each of these units were also specified. For example, the organization of a Mechanized Infantry Squad was depicted in Figure 8:

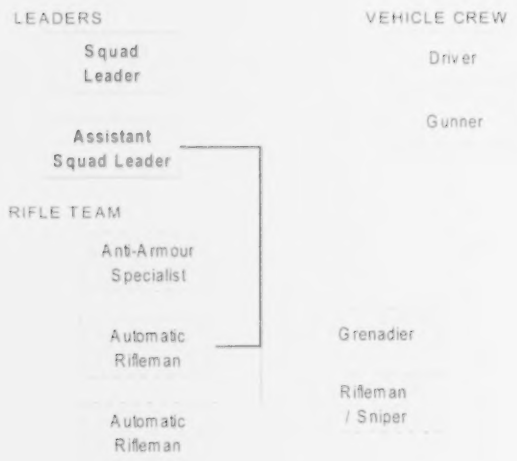


**Figure 8: Mechanized Infantry Squad Organization (Roth, 1992)**

As a product of examining these various military units, Roth articulated the features of these units that might impact on collective task performance as a result of time without training and turnover. These factors are tabulated below showing the hypothesized effect on collective skill retention with respect to time without training and turnover.

| Proposed Factor and Definition | Effect on Skill Loss as Result of Time Without Training and Turnover |
|---|---|
| Number of unit members | Higher numbers of unit members necessitate more learning. Therefore, the bigger the collective size, the more skills fading that will occur within a team. More skill loss over time in larger units, but less loss related to turnover. |
| Number of sub-teams in formal unit structure | The more sub-teams, the more need to learn about not only one's own sub-team's responsibility, but increased dependencies with the other sub-teams. As such, higher numbers of sub-teams will create more skill loss over time, and as a result of turnover than will fewer sub-teams. |
| Position redundancy in formal unit structure – extent to which unit members can directly substitute for other members | The more that members of a collective can substitute for each other, the less collective skill loss will impact on them, as the information and knowledge required by any individual will be less. More redundancy is associated with less loss due to training interval and turnover. |
| Number of equipment items used by the collective | Each item used requires knowledge. The more items, the more knowledge required, and so the higher potential for collective skill loss over time and as the result of turnover. |
| Number of collective tasks performed by a collective | With the more tasks required of a collective, the total pool of knowledge required increases. This need for knowledge increases the possibility that collective skill loss will occur within the collective as a result of time without training and turnover. |
| Number of individual tasks performed by members of a collective | The account is as above, but at an individual level. |
| Number of leaders in formal unit structure | Leaders are posited to be more likely to retain not only their own skills, but also those of other collective members. Hence, having more leaders within a collective will lead to less collective skill loss as result of time without training and turnover. |

**Table 12: Summary of Unit Factors**

| Proposed Factor and Definition | Effect on Skill Loss as Result of Time Without Training and Turnover |
|---|---|
| Number of sub-tasks and standards in task description – | When there are more sub-tasks, there is more for unit members to remember in order to complete the task. Therefore, more knowledge lost over time for tasks with more steps and more loss related to turnover. |
| Established vs. emergent nature of task performance - Tasks which are completed the same way under all conditions are established, and those which are completed differently each time, are said to be emergent. | Tasks with established properties can be easily "cook-booked", so that simply learning the steps to the task may be sufficient. Tasks which have emergent properties, however, require more knowledge as adjustments may need to be made for varying contexts. Highly established tasks require less knowledge, so are likely to have less skill loss over time, and as the result of turnover. |
| Average number of sub-teams per sub-tasks | The more sub-teams working on a task, the more need there is to coordinate activities, and to learn about the other sub-teams, their membership and their relationship to the whole task. As such, a higher number of sub-teams predict less collective skill retention. |
| Number of individual tasks required to perform collective tasks | Collective tasks with a higher number of individual tasks require more information and learning, so will be retained less well than collective tasks with fewer individual tasks. |
| Co-active vs. interactive task performance – unit members do similar (co-active) or different activities (interactive) in performing the task | More interactive tasks require more knowledge and learning about other team members and the division of responsibility. These tasks will show more skill loss as a result of time and turnover. |
| Potential for compensating or correcting errors during task | Tasks with more potential for correcting will have less skill loss associated with time and turnover, as diminished performance is addressed by other team members. |

**Table 13: Summary of Collective Task Factors**

The following factors were identified but not applied in the model.

| Proposed Factor and Definition | Effect on Skill Loss as Result of Time Without Training and Turnover |
|---|---|
| Aptitude | High levels of average individual aptitude will result in better ability to learn and retain knowledge, and should predict better collective skill retention |
| Turnover rate | Higher turnover will be associated with lower collective skill retention. |
| Experience performing collective tasks | Units in which members have high levels of experience may result in overlearning of collective tasks. This may result in higher levels of skill retention. This should reflect the average level of experience and the highest level of experience in the unit. |

**Table 14: Summary of Individual Factors**

### 6.3.2 Developing Regression Equations for Collective Tasks

Once this categorisation scheme for unit type factors and collective task factors was developed, regression equations were developed to predict the likely effects of inter-training interval and personnel turnover on collective task performance within specific kinds of units. Although the intent was to base these equations on actual performance data, this was not possible, and input from SMEs was used instead.

A subset of the collective tasks performed by each unit was used for which the available task description provided sufficient detail about how the task was to be performed. As this work was done

in the U.S., the task descriptions came from the training objectives for each task and the mission training plans developed through the Army Training and Evaluation Program.

Scenarios defining varying levels of inter-training interval and turnover were then created for each unit type. For large units, 52 scenarios were created for each, and 26 scenarios were created for each small unit. Within these scenarios, two inter training intervals were used: *low* (with 20 to 30% of the unit turning over each month) or *high* (50% or more of the unit turning over each month). Positions in which turnover occurred were also varied among senior leaders, junior leaders or non-leaders.

SMEs were asked to consider each scenario, and to estimate how well a specific unit or collective would perform on a collective task, considering the unit turnover as well as the time since training. The hypothetical unit performance was rated as "T" (trained), "P" (needs practice), and "U" (untrained) for each scenario, and estimations were distributed in each of these categories out of 100 total points available.

These estimations were completed under three assumptions: that the unit began at full strength, that each unit member was capable of completing each individual task, and that the task had performed proficiently immediately after training.

Estimates were completed for each of 235 collective tasks for each unit types by two SME's, working independently, and five SME completed these estimates, in accordance with their experience. The SME's were retired Colonels (2), Captains (2) and a Sergeant (1).

Estimates of inter rater reliability were conducted to ensure that the ratings of the 2 SME's were consistent. Inter rater agreement correlations were conducted for ratings within each unit type, and there were shown to be consistently high, ranging between .66 for the Mechanized Infantry Squad and .92 for the Armor Platoon.

The number of points assigned to the "T" category were averaged together, and these averages were used as criterion data for developing the regression equation. The predictor variables were:

- Number of months since training
- % turnover of senior leaders
- % turnover of junior leaders
- % turnover of non-leaders

The regression equation form used in this research was:

$$Predicted\ Y = constant + B_{ITI} + B_{SL}x_{SL} + B_{JL}x_{JL} + B_{NL}x_{NL}$$

This regression equation describes the probability that a unit will be trained if it performs the task under the specified conditions of inter training interval and personnel turnover. The B terms are the weights or coefficients for inter training interval, senior leader turnover, junior leader turnover, and non-leader turnover. The x terms are the actual values of inter training interval (in months) and turnover.

A stepwise regression procedure was used to develop the regression equations.[8] Predictor variables were included if they increased the coefficient of multiple correlation between the set of predictors and the criterion variable. Estimates were completed for 235 tasks, and regression equations were created

[8] Using stepwise regression is obviously problematic. Rather than forming predictions about which predictors were likely to exert influence and testing this, stepwise regression amounts to throwing all the predictors into the mix. Most critically, it is not clear that the results are necessarily helpful as a basis for theory development.

for each of the estimated tasks paired with the appropriate unit. Linear regression equations were adequate for describing the variance between SME performance estimates and the predictor variables, with the Average Multiple r ranging between .96 and .99 for the 5 units.

The average predicted skill loss due to inter training interval ranged from 1.89% for Light Infantry Squads to about 4.07% for Mechanized Infantry Squads. Over all units, the average performance decrement due to inter training interval, as predicted by the SME estimates was about 3% per month.

Understanding the average effect of turnover is more difficult, as the weights provided are based on varying numbers associated with leader turnover. Using an estimate of only 1% per month in all categories, the average effect of leader turnover within varying units ranged from -.35% to –1.69% for senior leaders, from -.077% to -.41% for junior leaders and from -.13% to -.23% for non-leaders, with the effect of turnover predicted to be somewhat more influential within a mechanized infantry platoon than within other units.

So, after this intensive process, regression equations representing the predicted amount of skill loss given differing amounts of time without training and turnover were created for each collective task within each unit.

### 6.3.3 Applying and Validating the Categorization Schemes

The next step in developing the model was to show that the factors identified were related to the retention predictions derived from the regression equations. SMEs first rated each of the unit types on the unit-type factors, and then rated the collective tasks on the collective task factors. Ratings on the unit type factors were completed by counting the number of sub-tasks in the task and the number of equipment items used by the unit type.

For the collective factors, the process was much more complicated, and required the development of several rating scales. To validate the model as a whole, Roth first attempted to validate classification of unit types and collective factors on the amount of collective skill loss.

A single score was created to represent the overall effect of the unit type factors combined (UTEP score). For this, the unit type raw scores for each of the unit type factors were converted into "high" and "low" effects indexes for both the inter training interval and turnover, based on the position of each score relative to the median on each of these 2 dimensions. If a given unit type factor was rated above the median in terms of its hypothesized effect on both ITI and turnover, it would yield a score of 2. The scores for each of the 6 factors were then added together to yield a total score ranging from 0 to 12.

For units with higher UTEP scores, retaining collective performance would be more difficult.

A similar process was used to develop a collective task effect prediction (CTEP score). SME's rated each of the tasks, and created scores for each task within each kind of unit. CTEP scores were divided into "high" and "low" effect categories, based on a cut-point approximately equal to the median for each task on the ITI and turnover dimensions. These "high" and "low" designations were then combined to give an index of the predicted effects of ITI and turnover on the specified task.

Higher CTEP scores indicate tasks with more collective skill loss over time and from turnover.

Individual factor scores from the unit type rating and the collective task categorisation ratings and the UTEP and CTEP scores were validated against the SME estimates of collective task performance change. The goal was to examine the extent to which the predictions implicit in the UTEP and CTEP scores (as well as in the individual factor ratings) would match with the predictions from the regression equations.

**a) Unit-Type Factors and UTEP Score Validation Against SME Data**

The first step was to work to validate individual factors related to unit type, as well as the global UTEP score created to represent unit type. A strong relationship between the prediction of retention in the SME estimates, and the unit type factors would be evidence for the validity of the classification scheme. An average beta weight was calculated for each of the 4 factors (ITI, turnover x3) across all collective tasks for each unit type, in order to establish the strength of each of the 4 factors for each unit type.

These average beta weights were then correlated with the raw data values for each unit-type factor and with the UTEP score assigned to each of 5 unit types.

| Unit Type Classification Factors | | Characteristics of Regression Equations Based on SME Estimates |
|---|---|---|
| UTEP Score | Correlated against | Average beta weight for effect of ITI |
| Number of Members | | Average beta weight for effect of Non-Leader Turnover |
| Number of Sub-Teams | | Average beta weight for effect of Senior Leader Turnover |
| Position Redundancy Measure | | Average beta weight for effect of Junior Leader Turnover |
| # of Equipment Items per Member | | |
| # of Collective Tasks | | |
| # of Individual Tasks | | |
| # of Leaders | | |

**Table 15: Analyses to Validate Unit Type Categorisation Scheme (Roth, 1992)**

This led to a total of 28 possible correlations, of which 10 were significant at $p < .05$, or close. The table of significant correlations is provided below.

| Correlations Between: | | r | N | P |
|---|---|---|---|---|
| UTEP | Senior Leader Turnover | -.82 | 5 | .044 |
| # of Members | Junior Leader Turnover | -.91 | 4 | .045 |
| Position Redundancy | Junior Leader Turnover | -.92 | 4 | .040 |
| # of sub-teams | Junior Leader Turnover | -.92 | 4 | .040 |
| # of collective tasks | Junior Leader Turnover | -.98 | 4 | .011 |
| # of leaders | Junior Leader Turnover | -.90 | 4 | .051 |
| # of equipment items/member | Senior Leader | -.76 | 5 | .064 |
| # of individual tasks | Senior Leader | -.83 | 5 | .042 |
| # of equipment items/member | Inter training Interval | -.86 | 5 | .032 |
| # of individual tasks | Inter training Interval | -.86 | 5 | .032 |

**Table 16: Significant Correlations Between Unit Type Categorization Variables and Average B Weights in Regression Equations for Unit Types (Roth, 1992).**

As this table shows, the correlation coefficient pattern is consistent, as increases in unit-type factors (e.g. larger teams) are associated with predictions of lower collective task performance in the equations predicting skill loss for a given unit type.

Moreover, all of the unit-type factors are significantly correlated with at least one of the equation terms. Number of equipment items and number of individual tasks correlate with both ITA and senior

leader turnover. The other factors correlate with just junior leader turnover, and no factors correlated with non-leader turnover.

Importantly, the overall UTEP score (meant to be a global indicator of the ITI and turnover on unit type) only correlated with senior leader turnover, suggesting that the UTEP score is a poor predictor of retention. This suggests, as one might expect, that leader stability is an important issue within units, as a predictor of collective skill retention. Overall, Roth argues that there is some evidence that the individual unit factors are related to collective skill retention, but little support for UTEP as a tool. However, the possible bias of SMEs (as leaders themselves), towards overestimation of the importance of leadership positions needs to be considered.

**b) Collective Task Factors and CTEP Validation Against SME Data**

The next step was to validate the collective task factors seen to influence collective skill retention. Again, an average beta weight was calculated for each of the 4 factors (ITI, turnover x3) across all collective tasks for each unit type, in order to establish the strength of each of the 4 factors for each collective task.

| For Each Unit Type Separately, | | |
|---|---|---|
| **Collective Task Classification Factors** | | **Components of Regression Equations Based on SME Estimates** |
| CTEP Score | correlated against | B Weight for Effect of ITI<br>B Weight for Effect of Non-Leader Turnover<br>B Weight for Effect of Junior Leader Turnover<br>B Weight for Effect of Senior Leader Turnover |
| Number of Sub-tasks & Standards | | |
| Established *versus* Emergent Rating | | |
| Number of Individual Tasks | | |
| Coactive *versus* Interactive Rating | | |
| Rating of Potential for Correction or Compensation in Task Performance | | |

**Table 17: Summary of Analysis to Validate Collective Task Categorisation Scheme**

These average beta weights were then correlated with the raw data values for each collective task factor for each unit type and with the CTEP score for each collective task. Out of many possible correlations, 20 were statistically significant and are shown in the table below.

| Unit Type | Correlation Between | | r | N | p |
|---|---|---|---|---|---|
| Armor Platoon | Established/Emergent Rating | Senior Leader Turnover | -.4754 | 64 | <.001 |
| | Established/ Emergent Rating | ITI | -.3520 | 64 | <.01 |
| | Number of Individual Tasks | Non-leader Turnover | -.2772 | 58 | <.02 |
| | Number of Individual Tasks | Senior Leader Turnover | -.2350 | 61 | <.03 |
| | Coactive/Interactive Rating | Non-leader Turnover | -.2520 | 61 | .03 |
| | Coactive/Interactive Rating | Senior Leader Turnover | -.3097 | 64 | <.01 |
| | Coactive/Interactive Rating | ITI | -.3016 | 64 | <.01 |
| Mechanized Infantry Platoon | Number of Individual Tasks | Junior Leader Turnover | -.3509 | 58 | <.01 |
| | Number of Individual Tasks | Senior Leader Turnover | -.2201 | 58 | <.05 |
| | Number of Individual Tasks | ITI | -.3325 | 58 | .01 |
| Light Infantry Platoon | Number of Individual Tasks | Non-leader Turnover | -.3218 | 44 | <.03 |
| | Number of Individual Tasks | ITI | -.3497 | 44 | <.01 |
| Light Infantry Squad | Number of Sub-teams per Sub-task | Non-leader Turnover | .6426 | 33 | <.001 |
| | Number of Sub-teams per Sub-task | Junior Leader Turnover | -.3065 | 36 | <.04 |
| | Number of Sub-teams per Sub-task | ITI | -.5186 | 38 | <.001 |
| | Number of Individual Tasks | Non-leader Turnover | -.4213 | 33 | <.01 |
| | Number of Individual Tasks | ITI | -.4052 | 38 | <.001 |
| | Coactive/Interactive Rating | Junior Leader Turnover | .3000 | 36 | <.04 |
| | Coactive/Interactive Rating | ITI | .2774 | 38 | <.05 |
| | Potential for Compensation or Correction | Non-leader Turnover | .3266 | 33 | <.04 |

**Table 18: Significant Correlations: Collective Task Factors and Regression Components.**

Correlations were mostly low indicating considerable variability, although results did show the expected pattern of negative correlations between the beta weights for the regression equations and increases in the collective task factors, even in varying unit types. Results are more consistent at the platoon level than for the smaller squad where there were several inconsistencies (e.g. positive correlations) and a lack of significant correlations. Roth's explanation is that this work may best describe collective skill retention at the Platoon level

The number of individual tasks performed by personnel within varying units, correlates most often with inter training interval, as well as with Senior Leader turnover. Ratings of task co-activity and interactivity are also frequently correlated with the regression equation weights. Again, however, there is no evidence that the combined measure of the collective task effect is at all correlated with higher collective skill loss (as indicated by the regression weights). Although any large battery of correlations is likely to show at least some statistically significant relationships, there is some evidence that the collective task factors as specified are correlated with the subject matter estimates of skill loss. However, the correlations are, for the most part, small and their practical significance should not be over-interpreted.

In conclusion, although efforts to validate these factors are brave, the results of these efforts are questionable at best. Consequently, it is very difficult to assess the validity of the proposed framework, and the categorisation approach merits further refinement and more effort at validation.

### 6.3.4 Empirical Evaluation

After this validation of the categorisation schemes, Roth worked to assess the empirical strength of the model by comparing the SME predictions of collective skill retention against actual performance data. In the first test of the collective task categorisation schemes with real data, predicted scores on the

individual collective tasks and the overall CTEP scores were validated against actual task performance data for Light Infantry Platoon tasks.

**c) Collective Task Factors and CTEP Validation Against Actual Performance Data**

Ideal validation of collective task factors would be to compare predicted scores on collective tasks (from SME's estimates in the regression equations), and the actual performance of a unit on those tasks. Performance evaluation data for Light Infantry Platoons had been preserved over the course of 12 training rotations at a training centre.[9] This enabled "*predicted to actual*" comparisons for selected platoon tasks.

Two platoon task performance measures were available from the training centre.

- The first was the ratio of task steps rated "GO" over all the steps rated on each of 1230 tasks completed by a Light Infantry Platoon unit task, ranging from 0 to 1 over a period of 12 rotations at the JRTC. These tasks matched the tasks used in the creation of the regression equations.
- The second performance measure was based on the number of sub-tasks scored "GO", using 859 tasks matching the Light Infantry Platoon tasks.

Two different analyses were completed.

In the first, "high" and "low" declarations were given to effects ratings on group variables with the expectation that higher CTEP scores and high effect declarations would be related to lower levels of performance. Median tests were conducted to assess the relationships between these variables. Results showed that only three factors that correlated significantly with the performance data: the number of individual tasks, co-active/interactive ratings and potential for compensation or correction.

This suggests that the number of sub-tasks and standards was not a good predictor of collective task performance, nor was the established/emergent rating. There was a statistically significant effect for the number of sub-teams per sub-task, but this effect was in the opposite direction from what was expected.

The second analysis looked at the correlation between the CTEP score and actual performance, using the prediction equations. The ITI was set to 3 months and the turnover (3 kinds) was set to 33% per month. These predictions were then correlated with the actual performance. The resulting correlation between the combined CTEP score and performance score was statistically significant but very low, ranging between minus 0.12 and minus 0.23. This suggests that the CTEP score is a poor predictor of collective task performance.

Additional analyses were conducted to compare the correlation between performance estimates made by SME's and the actual performance data. These analyses can be seen as an indicator of the validity of the SME estimates. Regression equations for the collective tasks in the JRTC data were applied using a common scenario of ITI (3 months) and turnover (33%). Results showed a consistent but very modest correlations between SME estimates and actual task performance scores ranging between $r = 0.14$ and $r = 0.36$. The statistical significance of the positive correlations suggests that when SME's estimated the retention of a given task to be low, actual performance of the task was also low. However, the low correlation shows that the SME estimates have only a very weak relationship with actual task performance.

[9] The time interval reported between sessions, and the total interval over the 12 sessions was not reported.

Correlations comparing the actual JRTP performance data and the CTEP scores were also conducted. These analyses suggest no relationship between the CTEP scores and the actual performance scores, $r = 0.031$.

**Summary Overview** - These validation results provide very limited evidence that the collective task factors as combined in this model are able to predict collective skill retention. There is some evidence that three of the six factors are correlated with predictions of skill retention but, overall the results of this empirical evaluation are far from convincing, and suggest that considerable work is still required to understand how, if at all, the factors proposed influence collective skill retention.

Although this work did use actual performance data for validation, it is difficult to assess the failure of the model to achieve clear-cut results. The interval elapsed between initial training and the actual performance measures taken is not specified. With so many tasks, factors, and measures, combined with puzzling analytic procedures, it is difficult to tease out underlying issues and suggest likely improvements, except to say that a less ambitious and more surgical approach comparing, perhaps two contrasting unit types, and two contrasting tasks, in greater depth and using customized rather than found empirical data would have been more productive approach in the long run. Although our search was unable to find any other research that uses this model in any way, such work would be helpful.

### 6.3.5 Applicability and Practicality

Although the empirical value of the model is questionable, this work does clearly lay out a framework for factors likely to impact on collective skill retention. The discussion of potentially influential collective task factors and the unit type factors is very helpful, and represents the best discussion of the factors likely to impact on collective skill retention found in our review.

From a practical perspective, the Roth research shows a lead in one approach to predicting the retention of collective skills. Although the rating process is likely to be very arduous, the sheer number of tasks and unit types rated for this research present evidence that it is possible for SMEs to use the proposed measures to make ratings of collective task retention.

The potential for using a similar approach in future work remains dependent on the ability to meaningfully represent the tasks performed within varying contexts. This requires having and/or developing detailed task analyses of each task and sub-task. In describing his model, Roth made the assumption that, within military contexts, many of these task conditions and standards already exist. This may or may not be the case in the military contexts touched by this review. As such, a critical part of preparing to use this model is to do the preparatory work of task and sub-task analysis.

In terms of the type of skills to which this model be applied, the 235 tasks used in this work seem to represent a broad spectrum of skills, ranging from perceptual-motor skills to more complex and primarily cognitive skills. In general, however, the focus appears to be slightly more on execution skills (e.g. clear a wood line) than on decision-making skills (e.g. prepare for tactical operations). The unit type factors identified also theoretically allow this model to be used in varying contexts, ranging from very small teams (e.g. tank gunnery crews) to higher levels of organization (e.g. command and control teams). The focus within this work, however, is at the platoon level and below. It is unclear how well more complex organizational structures and C2 tasks could be captured using the collective factors identified within this work.

In terms of the data needed to advance the model, there is clear potential for using the categorisation schemes proposed in order to predict collective skill retention, but these need validation. These categorisation schemes are plausible and have, at the very least, face validity. Moreover, using the

tools provided, it would also be possible to perform another validation of the categorisation scheme using real performance data, rather than correlating subjective estimates with more subjective estimates.

Surprisingly, however, this work does not appear to have been cited in associated research. In fact, it is unclear why this article's distribution and dissemination within the skill retention literature has not been more widespread, and why its contribution has not been more influential. It seems possible that the subjective basis of the model and the analytic muddle within the results presented may be at least partly responsible for its low profile within the skill retention research.

Despite the overly ambitious goals and the analytic shortcomings of this work, however, we would argue that this article makes two important contributions. First, and to its credit, the work addresses the prediction of collective skill retention with a model building approach that appears to be all but overlooked in the available literature. The creation of a conceptual model for collective skill retention is a significant contribution, and Roth's work represents the only attempt found.

Secondly, Roth's provides a good analysis of the factors likely to impact on collective skill retention. Many of the task factors cited are identified in other theory and research, but Roth adds specification of these factors, combined with articulation of how they are likely to be impacted by retention interval and by turnover within the collective.

## 6.4 Comparing Existing Models to the Categorisation Framework

In this section, we consider each of the three models reviewed in terms of our categorisation framework of factors to be considered in future models of collective skill retention. The categorisation framework is intended as a guide for thinking about collective and cognitive skill retention, rather than a formal specification of all the features to be considered. In fact, in the next chapter, we argue against including all of the defined factors (or even sets of factors) in future modelling attempts. In many ways, the grand scale is one of the main drawbacks of the Roth model. Rather, we propose the framework as a tool for considering the factors likely to impact on collective and cognitive skill retention in a broad range of settings. Actually beginning to understand such a phenomenon will require focusing concentrated efforts on a limited number of factors within a specific setting.

The categorization table shows that Nichol's model is the most rudimentary, as it focuses only on task difficulty, importance and frequency. Once the other models are incorporated, there is no important contribution of the Nichol's model that is not addressed in the UDA and/or the Roth model.

The original UDA model with some adaptation has the ability to address many of the collective task factors identified in this review. In addition, more recent research efforts extending the UDA model to cognitive (digital) skills extend the scope of the UDA model to address more cognitive skills such as situation awareness and problem solving. We have included recent research efforts as part of the potential predictive ability of the UDA model, even though the original version of the model did not incorporate these factors.

As the categorization framework also shows, the UDA model continues to focus on task factors (albeit increasingly elaborated task factors), ignoring several other critical influences on collective skill retention, such as training factors, individual learner factors, and the features of a collective's structure, organization, and composition.

Despite being at the relatively early stages of development, the Roth model provides the most comprehensive account of collective skill retention found in the existing literature. Roth addresses many of the factors identified in this review. Identification of factors related to collective units is

arguably the most important contribution of this work. The Roth model considers the number of collective members, as well as the number of leaders as potential predictors of skill retention. The argument that skill retention within collectives will be affected by the structure, organization, and composition of the collective is an important contribution. Personnel turnover within the collective is another unique contribution of the Roth model, and an important factor worthy of serious consideration for future models, particularly within the military domain. Turbulence, or changes in the roles and responsibilities within collectives is also a factor likely to impact on the retention of collective performance, though the direction of this effect will depend on the nature of the cross-training achieved. Moreover, the ability to move the task factors identified in previous models of individual skill retention into collective settings, and to articulate these factors at a collective level is also evident within the categorisation framework. For the future, Roth's model could be used as a spring board.

| | Factors | Models reviewed[1] | | | |
|---|---|---|---|---|---|
| | | N | ARI-1 | ARI-2 | R |
| Collective tasks and sub-tasks | 1. Number of collective tasks assigned to the unit | | | | ✓ |
| | 2. Number steps in individual sub-tasks | ✓ | ✓[2] | ✓ | ✓ |
| | 3. Availability of interstep cueing within sub-tasks | | ✓ | ✓ | |
| | 4. Predictability of sub-task procedures & conditions of performance | | | | ✓ |
| | 5. Number of discrete skills required by the collective task | | | | ✓ |
| | 6. Number of sub-units needed to complete sub-tasks | | | | ✓ |
| | 7. Interchangeability among collective sub-tasks | | | | ✓ |
| | 8. Interdependence among collective sub-tasks | | | | ✓ |
| | 9. Potential for error correction and resource re-deployment. | | | | ✓ |
| | 10. Need for information exchange among collective members | | | | |
| | 11. Cognitive complexity of collective sub-tasks. | | ✓ | ✓ | |
| | 12. Criticality of sub-task | ✓ | ✓ | ✓ | |
| Collective structure | 1. Structure of the collective (sub-units and levels of organization). | | | | ✓ |
| | 2. Number of people in the collective. | | | | ✓ |
| | 3. Leadership structure | | | | ✓ |
| | 4. Potential for role substitution | | | | ✓ |
| | | | | | |
| Collective member-ship | 1. Shared mental models of team members and team tasks. | | | | |
| | 2. External turnover and internal turbulence | | | | |
| | 3. Social environment in the collective. | | | | |
| | | | | | |
| Individual differences | 1. Aptitudes of collective members | | | | |
| | 2. Diversity of experience among collective members | | | | |
| | 3. Experience in collective settings. | | | | ✓ |
| | | | | | |
| Training received | 1. Level of learning after initial training. | ✓ | ✓ | ✓ | ✓ |
| | 2. Time since training: retention interval | ✓ | ✓ | ✓ | ✓ |
| | 3. Match between the training context and the retention context. | | | | |
| | 4. Training received as a collective | | | | ✓ |
| | 5. Training strategies used to achieve collective performance. | | | | |
| | 6. Acquisition phase of collective task | ? | | | |
| Other | 1. Number of items of equipment and their complexity | | | | ✓ |
| | | | | | |

**Table 19: Summary of factors likely to influence collective skill retention.**
**([1]Models: N = Nichols; ARI = Army Research Institute; R = Roth. [2]✓ = present in some form. ? = indirectly present.)**

None of the models adequately address training issues which are likely to impact on collective skill retention and although the importance individual differences in aptitude are noted in all 3 models, only the Roth model explicitly articulates the importance of these factors, even though those factors were not incorporated into the model.

As a whole, these models represent a good starting point to begin to understand how to predict the retention of skills within collectives over time. However, it is also clear that considerable effort and research will be necessary to make progress in this area. The next section presents some recommendations for beginning this process.

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# 7. A Way Ahead for Predicting Retention of Collective Performance

This section of the report begins by exploring broad considerations for development of an approach for predicting collective skill retention. The second part includes recommendations for areas of research and theory that would be beneficial to explore in more detail. The illustration below outlines the factors discussed in earlier sections in relation to acquisition, retention and re-acquisition.

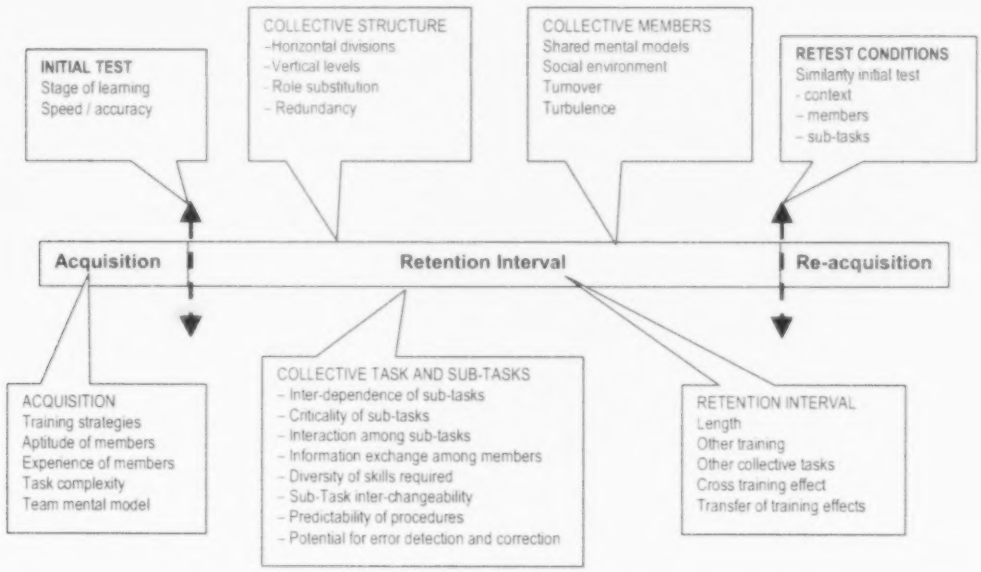


**Figure 9: Factors likely to influence retention of collective performance**

## 7.1 A way ahead

Before discussing any way ahead, some broad observations are appropriate.

The whole area of interest (i.e. training acquisition, retention and re-acquisition at the individual and group level) is replete with confusing and inconsistent results, employing often very simple or unrealistic tasks, and using subjects with inappropriate or unknown experience, aptitudes and/or skills. Methods are more often laboratory than field based, and inconsistently validated. Indices of retention and measures of performance vary widely, and seldom balance speed and accuracy. Individual training issues such as learning, acquisition, transfer, retention, strategies, performance, recall, forgetting, testing, and interference interact in complex and often little understood ways, and more complex interactions can be expected at the collective or team level.

Terminology is also inconsistent and confusing. Conceptually it is often difficult to determine whether one is reading about tasks, skills, sub-tasks, or aptitudes. The term "collective" itself is hardly

ever used, and no definition was found, except in so wide a manner (e.g. *two or more people interacting for a common goal*) as to overlap very largely with definitions of *team*, or *organization*. Whatever "collective" term one uses (team, organization, group, crew), training research is in the early stages with respect to either acquisition or retention, with progress being made at different rates. Research with respect to team mental models appears to be one of the most promising, though its translation to retention issues remains sketchy.

The significance of predicting the retention interval for planning refresher training may also be questioned, as may assumptions about the level of performance achieved for any collective task, but especially ones involving very large collectives. It seems probable, given the apparent infrequency of practice, the turbulence and turnover in personnel, and lack of consistency in the conditions of practice, that performance on collective tasks will seldom reach the ultimate goal of training: autonomous performance. In other words, collectives or teams seem likely to dwell, in normal training, in a stage where procedures are being learned and team mental models built and the cognitive or associative stage may have been reached but that autonomous performance is some way ahead. In fact, one could even argue that collectives may not be able to reach Anderson's autonomous stage until collective membership stabilizes, and until repeated practice under consistent conditions can be undertaken.

This begs the question, if we are to model retention for the purpose of assisting the planning of unit level training of collective tasks, what aspects of retention are best modelled and measured. The most fruitful approach would appear to build on the team mental model research and to predict retention of knowledge for areas outlined in the current team mental model literature among different team members, and retention of performance for critical and interdependent tasks.

We would also argue that *type of training* should be considered as part of the modelling process. It seems likely that training approaches to maintain individual knowledge and skills relevant to maintain team performance for a given collective task at the cognitive or associative stage are likely different from those required to move it to the autonomous stage.

Talking about "collective knowledge" and "collective skills" can be misleading. Rather individuals have knowledge and skills that contribute to team performance. For instance, to form a team likely to perform well on a given collective task, one would probably pick individuals with proven experience and skill in the different individual tasks (especially critical or interdependent tasks), and in the likely context of application. (To make the pick would require a good overall knowledge to the sub-tasks and their interdependencies, and the context in which the collective task might be performed – i.e. have access to a comprehensive team task analysis.)

A team that scores high on relevant individual skills and knowledge will likely perform well on their collective task, even without practice together. Such a team will likely perform better once they get to know how each other react and have a chance to generate a common idea about how to deal with contextual issues: i.e. plan together.

Moreover, individuals on a newly formed team who are experienced with teamwork and with the collective task in question, are still likely to know what to look for in other team members and what questions to ask about interdependent and critical tasks and the context in which they will have to work. This may enable a team of experienced individuals to gel more quickly as a team. (One might describe this as making a rapid progression from one learning stage to another.) Refresher training for such a group might look quite different from that for a group of individuals largely without experience, and progress at a different rate. If such a scenario seems plausible, then the question is,

what experience is relevant for what collective tasks, and what type of training is most appropriate. That question needs careful examination and empirical data before any serious modelling takes place.

The temptation is strong to advocate starting completely afresh, but that approach is probably what opened Pandora's box in the first place. However, it does seem necessary to step back and look at the bigger picture to determine where to start and what comes first.

The first nettles to grasp seem to be matters of scope and terminology. As a point of departure, this may result, initially, in a set of fragmented ideas, but the groundwork needs to be laid out so that the elements can subsequently be brought together.

## 7.2 Scope

In terms of scope, to us, the goal appears to be essentially a practical applied one: to help military training planners at the unit level determine what tasks to train, how and when. Thus, we should first better understand the context within which such planners have to work or risk undertaking tangential research. Priority questions that come to mind include the following. An important first step in any research program will be to frame the answers appropriately.

- *Definition of the planning "Unit"*. Presumably this will be the level of unit at which there is some autonomy over what to train and when. We assume that this, in the army, is at the level of an infantry battalion, or its equivalent, and in the navy, a ship.
- *Identification of goals / needs of unit planners*. Perhaps broad training performance goals can be thought at two levels: *maintenance* and *mission*. In such a formulation, a unit is required to maintain performance on a range of prioritized collective tasks to some minimum background level and then to improve performance on a sub-set of these tasks to a mission standard. This is probably done by setting out, within goals from higher authority, an annual planning schedule that specifies what tasks each sub-unit will learn / practice, how this is to be done (with reference to training manuals) and the access to resources required.
- *Unit training cycle*. Within units, military training appears to cycle within and between years for both individual and collective tasks. A common starting point is the end of summer period, during which individuals upgrade courses, postings occur, and vacations are taken. After this, the unit re-constitutes (to some degree), first hones individual skills, then small group skills, culminating prior to the next summer in whole unit training, and training in conjunction with other units.

This *within-year* cycle may be supplemented by a *between-year* cycle from operational period to operational period. The *between-year* cycle will undoubtedly vary with operational demands and the time frame may be compressed or expanded. A starting point might be taken as end of a period on operations. The cycle would then start with one year spent re-forming and re-training individual and small team skills, followed by a year working up to the required performance on sub-unit tasks culminating in training on collective tasks involving other units. The third year in cycle is spent on operations, with in-theatre training. As the second year progresses, scheduling and planning for training would be guided by likely priorities for the coming operations.

If this outline is accurate, the challenge for unit training planners is to focus training on performance of likely operational tasks, under mission conditions. Furthermore, planning and prediction issues such as the positive or negative effect on retention of other individual and group training activities undertaken during the retention period need to be studied in the context of particular training cycles

and programs. The same is true in considering the impact of turbulence and turnover within and between sub-units involved in collective tasks.

- *Delimitation of focus among potential collectives.* Leaving definitional problems aside for the moment, there is a need to delimit study in terms of what sort of unit we mean by the term collective. Consensus seems unlikely, but aspects might include the stability of the structure, the number of personnel in the collective, and number of levels of organization. For study purposes, we would suggest that a common type of military collective should be chosen, to ease gathering of robust data sets for research purposes.

We would suggest that, at least for the time being, research should be limited to military groups that are relatively small (say less than 30), have no more than two structural levels, have a structure that is stable, and tend to endure and work together as a unit. This would permit research on collectives to be structured around a more manageable number of variables, and would include, for example, army units of platoon but not company size, departments within ships, but not ships as a whole[10]. We would also exclude collective groups that tend to work together only occasionally and formed in somewhat unpredictable ways from specialized sub-units. This might include army combat teams, battle groups, brigade groups that comprise different specialist sub-units that may combined or re-combined at short notice, and seldom train together in their entirety.

It may be possible to consider these constraints on collective size and structure as a something of a "window" that may be shifted up or down over a given organizational structure. Something like this is done, for instance, for staff exercises (so called CPX), where training goals are limited to collective members responsible for command and co-ordination aspects of a collective task, not the performance of everyone in the collective. A benefit of such an approach would be to allow a focus on C2 tasks, while retaining study control over important structural factors likely to affect acquisition and retention. Related sources of research might include studies of management teams and committees, in relation to performance of collective tasks at a higher levels of an organizational structure, performing more cognitive tasks of the problem solving and decision making variety, where information exchange and co-ordination among critical interdependent sub-tasks is a priority.

## 7.3 Terminology

There are several terminological issues that need sorting out, or at least fixing clearly for the purposes of comparing research outcomes, and facilitating discussion of the problems involved.

***Tasks*** The term 'task' leads to confusion between the task of the collective and the sub-task of the individual within the collective task. There needs to be some consistent terminology to differentiate these. This may be as simple as task and sub-task, used consistently. Tasks or sub-tasks can be seen as having some particular combination of goals, procedures, using particular equipment, and requiring a set of underlying (more generic) skills, and relating to the functions to be fulfilled.

Further distinctions are needed: for example among tasks that are performed largely in isolation from other individuals and those which depend on interaction with others.

There are other '*task*' related terms appearing in the literature that need attention: not all mutually exclusive. Among these are task structure, task analysis, task interdependence, task flow, task

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[10] Departments in ships may prove particularly valuable from a research point of view, because the watch system would permit longitudinal comparison of teams under close to identical conditions and tasks, taken over a period of a few days.

criticality, and task importance. In one way or another these terms are inter-related and emerge in different ways in the literature. For example, task *importance* is used to refer to the potential of non or poor performance to impair overall job performance, or affect safety. This overlaps somewhat with the idea of task criticality, where a sub-task is on the critical path for timely completion of the overall collective task. Analysis of task flow at the functional and/or team level is used to identify sub-task interdependence, importance, or criticality. It is clear that understanding of certain factors thought critical to the effect of retention of sub-task performance will depend on a preceding team task analysis. Many of these terminological issues are probably best resolved by the choice of a team task analysis method.

***Skill*** A skill may be understood as underlying performance on some task or sub-task, but being necessary rather than sufficient to achieve a required level of task or sub-task performance. Thus, a very skilled marksman may not show appropriate performance on some sub-task requiring marksmanship. On the other hand, a given skill may underlie performance on several quite different tasks. The models and literature reviewed sometimes slide disconcertingly between the two slippery concepts (task and skill)– but for the most part, deal in "tasks" (see preceding bullet). Someone who is deemed to be skilled marksman, for example, demonstrates this by showing proficiency at certain sub-tasks. Another, sometimes confusing, distinction separates knowledge, rules and skill – sometimes as stages of learning, sometimes as behavioural options contingent on circumstances. Thus, skills can be seen as autonomous and largely unconscious behaviour based on internalized rules and knowledge and reached only after extensive learning and practice. Where to place the dividing line between a skill and a task or sub-task is an issue: any choice will be somewhat arbitrary, but should be consistent.

Measuring performance on some task or sub-task is the only way to demonstrate that training has been effective (or retained). Task performance is the result required on the day. The need to consider both individual and team performance further complicates the measurement situation. The question arises whether it is really meaningful to speak of *collective skills*, as such, as opposed to measures of overall *collective performance* and individual proficiency in key individual tasks, which may be interactive (e.g. the task of co-ordination).

Military training at the unit and collective level appears mostly task, rather than skill based though, inevitably, task based training will practice generic individual skills. For collective tasks, refresher training of team or sub-task individual knowledge or skills that are generic to several high priority collective tasks is likely to provide greater return on training investment than training collective task by collective task. Interest in retention then turns from performance on collective tasks to performance on tests of common sub-tasks, or retention of knowledge for, say, procedures related to critical, interdependent, or interactive tasks. For this to be effective, the relationship among skills and tasks needs to be established first for the collective tasks of interest – through some form of team task analysis.

***Knowledge vs. information***. Performance of an individual or collective task and its related sub tasks is likely to require acquisition and retention of *knowledge* (tacit or declarative*)* of procedures or rules. The task (skill) itself may involve exchange, compilation or modification of *information* in some way, based on that knowledge. These terms carry different implications that need to be clearly separated – this not always the case in the literature.

Retention can be addressed at a number of different levels (possible related to qualitatively different plateaux of learning or decay). One level is the retention of the knowledge needed by the team to perform their collective task (i.e. mental models among the team for task procedures, capabilities and roles of others, etc). This knowledge may, in turn, be related to the retention of autonomous performance on the sub-task or task. If so, then study of retention for both knowledge and

performance, may permit more surgical diagnosis of retention intervals for the different components and related refresher training needs. For example, classroom refresher training of declarative and/or tacit knowledge related to team mental model components for a given collective task for a given class of collective member may represent a more cost effective approach to maintaining overall collective performance over longer intervals in the field. To answer this requires empirical data on such relationships. Retention curves related to turnover and turbulence may also be susceptible to this sort of examination: i.e. periodic updating of the team mental models of current team members with respect to the roles and capabilities of new and old team members, for the collective task of interest.

***Measures and indices***. Appropriate and accepted measures and indices of retention of different aspects of collective performance remain to be determined. Issues include whether to pitch measures at the level of group or individual performance, how to combine or separate speed and accuracy measures, whether to focus on both knowledge and performance, and process or outcome measures.

Another question is how any measures might relate to qualitative differences in the stages of learning (and decay?) and, in turn, to prescriptions for refresher training. In other words, is retention to be measured in terms of a percentage of earlier performance, or in terms of the level of regression from a more or less unconscious autonomous stage back to an associative stage dependent on declarative knowledge. There is also the need to know what level of learning is to serve as the starting point for retention. As noted earlier, collectives have been described as in a constant state of change in terms of membership, and collective tasks as being practised over long intervals under very different conditions. This raises the question of whether collective tasks, even simple ones for small collectives, ever reach the autonomous stage of learning, except after a period of continuous operations with constant team membership for a limited range of collective tasks.

With limited training time available, and limited opportunities for training as a collective as whole under realistic field conditions, what will provide the greatest (or any) return on refresher training? Would it be best to refresh selected individual tasks on the critical path for collective performance or on interactive tasks performed among selected members of the collective. Will knowledge comprising the different elements of team mental models decay at the same rates, and will refreshing of different knowledge sets contribute to retention of performance on the overall collective task? Answers to all these questions are needed as the basis for an effective model and to support planning of collective refresher training.

***Cognitive skills / tasks***. The term "cognitive" is used in different ways in the literature. On the one hand, it is used to refer to a class of tasks such as problem solving and decision-making that emphasize manipulation of information in some form. This description appears to be reserved for more complex tasks that are difficult to proceduralize, and often contrasted with simple perceptual motor tasks. On the other hand, the term is also used to refer to a set of presumed mental resources employed in any task, such as attention, memory, and information handling. The way in which cognitive aspects of collective tasks are to be defined needs to be established for conceptualisation of future collective training research, and to know how to interpret existing research. Our viewpoint is that cognition is an aspect of many collective sub-tasks and, likely, all collective tasks (if only for co-ordination purposes), and not just selected collective tasks. Thus cognitive issues are best dealt with as an integral part of modelling collective tasks, not as a separate category.

***Communication and information exchange***. In military terms, communication has often been equated with radio-based skills such as voice procedures, and network knowledge. In functional terms, radio communication is simply one method of exchanging or acquiring information, with certain advantages and disadvantages. Effective information exchange involves much more than working a radio net and lies increasingly at the heart of many collective tasks as sensor, software, and

communication technologies advance. The concept of information exchange should probably be broadened to incorporate all aspects of information handling within a collective: for both individual and interactive sub-tasks that affect overall collective performance.

***Team, group, organization, collective, unit.*** The concepts and definitions associated with these terms overlap to such a degree that one forced to wonder about the need for the term "collective" at all. The effect of its use in this project was to confound the search for relevant material: most of what was found related to teams, small groups, or organizations. No distinguishing feature of "collectives" was found to justify another term. The only unclaimed conceptual territory appears to be "a loose and temporary grouping of different organizations or teams of differing sizes or specialities to achieve a common goal": But this is not the sense the term has been used in the few "collective" articles found in this search or, apparently, in their secondary references.

We believe that interest and conceptualisation should be refocused on the more widely accepted terms of "organization" and "team" and the term "collective" either more systematically related to these other concepts or, more likely, discarded altogether. This would allow the net to be cast wider for existing research on issues relating to, for instance, organizational rather than collective structure and the wide literature on effectiveness of management and other teams, the surface of which was only scratched in this literature review. It may also reveal models of organizational and team structure that can be put to good use.

## 7.4 Existing approaches

In general, none of the existing models can be considered adequate to use, on their own, for predicting retention of collective performance.

- The Nichols model is simply not complex enough to be able to account for all the important factors.
- The UDA model of individual skill retention is much more elaborate, and the factors in that model might be adapted to the issue of collective performance, especially where individual tasks critical to collective performance are concerned. More recent efforts to extend the UDA model encourage that conclusion, but do not go far enough to capture the broad range of factors influencing retention of collective performance. More critically, as far as we could tell, the UDA model still needs broader validation.
- The Roth model (1992) is the most comprehensive model dealing with collective performance that we found. However, despite its conceptual promise, the Roth model omits potentially important factors. Also, validation is very limited and subjectively based, and, as far as it goes, does not support the model as a good predictor of collective skill retention.

## 7.5 A research program

Looking at a way ahead, we have chosen to present this in the form of an evolutionary 3 year research program based on the assumed structure of a one year military training cycle. The overall purpose would be to gather empirical data on retention of team performance, develop methods of analysing team performance issues, and to model retention of team performance and relate this to the provision of planning support for unit level training.

To achieve these goals, we advocate a narrowly focussed longitudinal approach set in the overall context of successive training years and believe that model building should be interleaved with

gathering of empirical data on two, small and representative collective structures, and two contrasting but common collective tasks.

For the purposes of the current work, data should be gathered for two actual collectives on the range of practical predictive factors outlined in this report. This should be done in the context of the annual (or longer) unit training program for the specific collectives chosen in order to examine the impact of as full a range of factors as possible operating during any given retention interval. Data should be gathered on retention of the overall collective task and sub-tasks in terms of speed and accuracy of performance, and retention of team related knowledge for the collective tasks chosen.

The foundations of the approach proposed would be a detailed analysis of the training cycle, the collective structures, and the collective tasks. A detailed team task analysis would identify critical individual, interdependent, and interactive sub-tasks. Retention of performance on these would then be examined in relation to a given annual training program, and an estimate obtained of different elements of the program (such as training on individual skills and related collective tasks) the likely impact on different aspects of retention of individual knowledge and collective performance. Retention of actual performance and knowledge would be tracked at appropriate intervals as well as other potential influences on the retention of these tasks over the training year, such as turnover and turbulence.

The specific goals of this work would be, for the collectives and collective tasks selected, to:

- Analyse needs of unit training planners.
- Analyse annual training cycles with respect to training collective tasks.
- Identify and apply a team task analysis approach to determine sub-task criticality and interdependence, and the nature of cognitive and interactive skills required.
- Identify the knowledge required for an effective team mental model.
- Gather data on changes in collective task performance over the annual training cycle and relate to selected factors thought likely to influence retention.
- Examine the applicability of existing models of individual and team retention to critical collective sub-tasks.
- Study the effect of factors related to the retention interval on retention of performance on individual knowledge, and critical and interactive sub-tasks.
- Study the effect of other factors: include task and sub-task factors, collective structure, individual differences among collective members, and training methods.
- Examine the practicalities of gathering and using existing data to study predictive factors such as membership turbulence and turnover and individual differences..
- Frame, evolve and empirically validate a model for predicting retention of performance of collective tasks and predicting related training requirements.
  Use task modelling software such as "Micro-Saint" as a tool to examine the potential impact of different retention on critical, interactive, and interdependent sub-tasks
- Develop and evaluate a decision support tool for unit planners for collective training.

These goals and approaches are outlined as a three year plan, in the table below.

| | Item | Comments |
|---|---|---|
| *YEAR* | Analyse unit training cycle and planning. | *May exist in literature* |

| | | |
|---|---|---|
| *ONE*<br><br>*Planning and preparation* | Extend literature search/review of team & organizational structure issues. | *Choose a suitable team task analysis method.*<br>*Establish recommendations for team training approaches.* |
| | Choose two contrasting team structures | *Relate to retention factors* |
| | Choose two contrasting team tasks. | *Relate to retention factors* |
| | Conduct team task analysis to determine:<br>–critical individual tasks<br>– interdependent tasks<br>– Interactive tasks<br>– measures of team and individual task performance (MOPS)<br>– knowledge required for team mental model for task. | |
| | Determine access to turnover and turbulence data | |
| | Obtain / analyse unit annual training plan to predict effects on target team and individual tasks. | *September start date?* |
| | Identify specific units to be studied. | |
| | Use UDA / Nichols / Roth models to predict retention of key sub-tasks. | |
| | Establish recommendations for team training approaches. | *Based on extended literature* |
| *YEAR TWO*<br><br>*Initial data gathering.* | Identify background aptitudes of team members. | *Use recruit aptitude scores?* |
| | Measure individual and team task performance at start. | |
| | Test performance at standard intervals | *Once a month?* |
| | Track turbulence and turnover over training year | |
| | Track all training received and relate to team tasks and sub-tasks. | |
| | Analyse data in terms:<br>- impact of factors<br>- predictions from UDA / Roth / Nichols | |
| | Refine team retention model. | |
| | Draft annual planning tool. | *Build on tools in literature* |
| *YEAR THREE*<br><br>*Controlled data gathering.* | Plan idealized training cycle for two tasks | |
| | Conduct training using that plan | *Controlled comparison* |
| | Track performance as before for target team and control team. | |
| | Assess UDA, Roth, Nichols<br>Refine model. | |
| | Refine planning tool | |

**Table 20: A three year program of research**

### 7.5.1 Identify a research context

The research context needs to set in terms of the collective structure, collective task, and training program.

**Collective structure.** For practical and economic as well as study design reasons, we advocate conducting initial work in some depth but on a limited number of collective types. The program should start with as few as two types of collective that represent a contrast in terms of influential structural factors such as the number sub-teams, the number of organizational levels, and /or the degree of specialisation required. Ease of access for repeated longitudinal data gathering should also feature in the choice, with common / numerous collectives having a higher priority for choice. In Canada, this might result in collectives such as infantry platoons, armour or artillery troops being the most probable candidates.

However, the choice should consider issues related to gathering of viable empirical data. Although army units might be the current focus of priority, looking from a tri-service point of view merits consideration. Theoretical issues should remain constant across all applications. Instances why inclusion of study of small navy teams might have advantages include the naval watch system which permits study of different teams under identical conditions for identical tasks, and the existence of sophisticated navy team training simulators used for both initial work-ups among ship teams (i.e. to reach initial criterion) and re-fresher training prior to departure on a mission. Incorporating team training measures as standard practice for all simulator training and archiving the results might greatly benefit long term research.

Initially, statistical issues should probably be treated in qualitative and descriptive terms, but later research and validation will need to consider analytical statistics and sample sizes – perhaps comparing across contributing countries. Choice of a commonly occurring type of collective group should ease later statistical challenges. However, the choice should be made after a systematic review of the options. Later, if some fundamental relationships can be established, the range of collective type may be expanded.

**Collective tasks.** For the same reasons as above, the program should start with two contrasting types of collective task, representing, for instance, different degrees of interdependence among sub-tasks. The range of tasks under consideration will depend on the type of collectives selected. Once again a systematic review of the options should be conducted. Tasks for which ready access to suitable training simulators exists for evaluating individual tasks offer potential advantages.

**Training program** There are three reasons for needing to set the study in the context of the overall training cycle over which collective tasks have to be retained. First, the global goal is to provide decision support for planners of unit training programs. This significance of this point has been discussed elsewhere in this section. Second, many potential factors relate to events during the retention interval, in particular for positive and negative transfer of training from other training on individual and collective tasks but also in terms of changes in the membership of the collective. The natural choice appears to be to use the context of a specific annual training cycle for a specific major unit, within which the training of the collective type and task of choice is conducted. The third reason is to take advantage of the already extensive training documentation available in most military settings with respect to description of training objectives, standards of evaluation, training manuals, simulation facilities, and, possibly, pre –existing data bases on matters relating to the research questions posed, particularly profiles of collective members. The latter might include aptitude data, records of qualifications and training results, operational experience, computerized records from which turbulence and turnover data can be derived, and others.

### 7.5.2 Extend knowledge of existing research

Concerns have been expressed several times in the report that only the surface has been scratched for relevant organizational design, communication behaviour, and team work research. We strongly recommend extending the literature search to focus on such issues as part of the preparation for this research program. In particular, we recommend a closer examination of research into team training and team mental models.

Review of existing approaches to optimising training strategies will also merit investment with respect to providing support to unit training planners. Work by Matto and Moses (1997), for example, presents a procedure called Training Strategies Optimisation Prototype (TSOP) to be used by unit level commanders in order to optimisation proficiency at a collective level. Employing this strategy involves feeding in specific inputs, including initial proficiency, training method utility, skill

degradation, training method costs and resource availability. The output of the approach is information about the optimal training strategy given the inputs. Estimates of initial proficiency, however, are based on a commander's view of skills as having been trained, being in need of practice, or being untrained. This fairly broad and subjective system of assessment may well lack the degree of precision needed but consideration of such approaches are potentially important in the context of the applied goal of this research.

### 7.5.3 Analyse collective team and task structure

It is clear that any future research needs to be set against a better understanding of the nature of the sub-tasks (especially in relation to their cognitive aspects) in any overall collective task. Sub-tasks need to be identified and considered in terms of their acquisition and retention, relevant knowledge, interdependence, and criticality. The presence of interaction among individuals and within and between sub-groups will also be important, as will be the level of information exchange. Without a comprehensive understanding of the way in which a collective task knits together and the way in which its completion relates to its sub-tasks, any future research is likely to be fruitless. This implies the need for a comprehensive team task analysis. An early step in any research therefore would be to establish a suitable team task analysis method, and apply it.

The use of flowchart and swim lane depiction methods to analyse team or collective tasks is not new. Such approaches have long been advocated as a method to depict the processes that teams use during the completion of missions and for project planning using approaches such as critical path analysis. For example, Microsoft Project appears to have the potential to form the basis for some aspects of the required analysis.

A conventional task analysis or project management approach, however, will only go so far in understanding a collective task. What is also required is a way to represent the sequence of steps that, taken together, comprise a collective task. What is needed is a method to capture individual sub-tasks as well as the task interdependencies related to roles within the collective (Salas and Cannon-Bowers, 2000; in Paris et al., 2000). It will also be important to understand cognitive components of collective sub-tasks using some form of cognitive task analysis at the team level.

For this reason, an important step in the research program will be to identify suitable task analysis methods. A frequent criticism of applying conventional task analysis methods to a team is that critical teamwork behaviours (e.g. interdependence, co -ordination etc.) are not included (Brenner et al., 1998). Other authors believe that task analysis may be appropriate within teams if it establishes a link across job tasks (Dieterly, 1998).

Paris et al. (2000) argue that capturing skills within teams requires an approach that is multilevel and dynamic. Team task analysis is the first necessary step. This process provides information about team learning objectives and competencies, and specifies the cues, events, actions, co-ordination needs and communication flows for good teamwork. Moreover, a team task analysis promotes an understanding of interdependency and works to distinguish collective team tasks from the individual tasks. Several approaches have been enacted in efforts to better measure team skills (e.g. Annett, Cunningham and Mathias-Jones, 2000). These need to be examined and a choice made.

The measurement of communication and co-ordination only addresses the issue of observable behaviour, and leaves the larger area of the inferred processes (e.g. shared mental models) untouched. The extent to which this matters may depend on whether the focus is on measuring learning (and retention of learning) or on performance. There may be many military contexts (e.g. with tank crews) where the performance of a given task is all that matters. Either a gunnery crew is able to hit the target or not. In a more

complex context, non-observable processes such as decision making and the degree to which collective members share mental models may be a better predictor of retention of collective performance.

Annett, Cunningham and Mathias-Jones (2000) employ Hierarchical Task Analysis for Teams to identify the components of tasks that must be completed or are best completed via teamwork. Teamwork, in this context, is loosely defined as "*communication between, and the co-ordination of actions of, members of the team*".

### 7.5.4 Create suitable measures and indices

Consideration is needed of suitable measures and indices for:

- Factors to be considered in modelling
  (features of collective tasks, collective structure, individual differences, training)
- Performance on collective tasks and individual sub-tasks for speed and accuracy

These must provide both a practical means by which to gather data for research and for unit training planners, as well as provide utility for research and for a decision support tool for unit planners.

Preliminary planning should select or create suitable evaluation criteria, measures, methods and standards. Some may be drawn from the military training literature for the collective tasks chosen. Others will have to be developed for the purpose of assisting unit planners determine training strategies and schedules, or to examine underlying research issues.

A particular challenge will be obtaining measures of team performance. Team performance has been measured along two main dimensions (Paris, Salas, Cannon-Bowers, 2000), using either measures of an individual's ability to perform specific tasks, or with team measures, which focus on co-ordination requirements and between team measures for given tasks (e.g. backup, information flow, correction of errors). Teamwork measures also frequently make the distinction between outcome measures of performance (were task objectives successful?) and process measures (how was the task completed?). For C2 work, process measures have been shown to be more practical to control, measure and interpret (Matthews and Webb, 1997) with information exchange, situation awareness and decision making identified as key processes.

There are a number of potential sources of error in the measurement of collective performance which can be considered (Turnage et al., 1990). A particular problem for retention at the collective level is the difficulty of assessing the stability of skill acquisition curves. Instability of the curves means suggests variance in measures unrelated to skill loss and due to varying levels of acquisition. Within teams, Turnage et al. (1990) argue that any measure of team performance is actually comprised of 3 separate individual components. Each of these factors contributes both true and error variance toward the measure of collective performance.

- proficiency of individual team members on individual tasks
- proficiency of individual team members on team tasks
- learning as a result of the continuing practice of the team as a unit

Team output measures may also be unduly affected by the performance of the "weakest link" in the team in terms of performance on critical sub-tasks that may reflect problems unrelated to team performance such as equipment problems. Turnage et al. (1990) specifically addresses the complexities of performance measurement with respect to military training, and this work provides a starting point from which need to be considered when consider collective performance measurement. The ability to understand collective retention will depend, in part, on an adequate systems of measurement for

collective performance in general. This system could apply to a wide variety of military specialities. According to Turnage et al. (1990) such a system does not exist.

## 7.6 Conclusion

A search of the relevant technical databases for studies of collective skill retention revealed only one directly relevant research report. This and other models of individual skill retention were examined against the background of military training and the long standing, wide and often contradictory literature on acquisition and retention of individual performance.

The broad conclusion of this work is that collective performance should be considered in terms of individual sub tasks as well as overall collective performance. Individual sub-tasks include those performed in isolation by collective members and sub-tasks requiring interaction among collective members. The effect of these individual tasks on overall collective performance will depend on the criticality and level of interdependence of these sub-tasks with respect to the overall collective task. Understanding these relationships among particular collective tasks for particular collective structures is a pre-requisite of effective study of retention of collective performance, and requires selection or development of a suitable team task analysis approach.

There are large of number of factors with the potential to affect both acquisition and retention of performance on collective tasks that may be categorized as those affecting the collective task and its sub-tasks, collective structure, the collective membership, individual differences, and the type of training provided before and during the retention interval on the task of interest and others.

Examination of the existing modelling approaches concluded that these are neither comprehensive enough in scope nor sufficiently well validated to use as a solid foundation for future work on predicting retention of collective performance.

A limited review of the broader literature on team and organizational issues related to the acquisition and retention of team skills, concludes that use of the term "collective" is very rare, and appears to contribute little added value to examination of team and organizational issues and, rather, distracts attention from the already extensive literature in these areas. In particular research on team mental models and their relation ship to training of team performance is an area that merits examination in more detail as the foundation of research into retention of team performance.

To fulfil the global goal of developing an effective decision support tool for unit planners and modelling retention of team performance under conditions typical of military training, a three year research effort is recommended with the following features:

- Extend the literature review into related team and organizational issues.
- Select or develop a suitable method for team task analysis.
- Analyse military unit training cycles and the needs of unit training planners in detail,
- Establish baseline data on internal turbulence and external turnover in military units.
- Develop appropriate measures of performance for individual and team retention.
- Conduct a longitudinal study over a unit training cycle of two contrasting collective types for two contrasting collective tasks.
- Use data gathered to build a model of retention of team performance and to evaluate the potential contribution of existing models of individual retention to predict retention of collective performance.

- Validate this model in the second year of study
- Develop and evaluate a decision support tool for unit training planners

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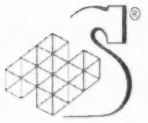

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14. ABSTRACT

(U) This review was conducted under the direction of DCIEM (Defence and Civil Institute of Environmental Medicine). Within the ultimate goal of fielding a validated model to be used by military personnel to schedule training of collective tasks, the purpose of this project was to review publications from the military research and development community concerning retention of collective and cognitive skills. Contributions from the general scientific literature were also considered.
The report is organised around sections considering training in the military; the nature of collectives and collective tasks; development and retention of collective performance; factors affecting retention of collective performance; existing models of collective performance; and recommendations for a way ahead.
A broad range of factors with the potential to affect retention of performance on collective tasks was considered. These factors were categorised as those affecting the collective task and its sub-tasks, collective structure, the collective membership, individual differences, and the type of training provided before and during the retention interval on the task of interest and others.
A brief review and discussion of the general literature on team work, team mental models and organisational issues suggests that retention of performance on individual sub-tasks will be strongly related to retention of overall collective performance – particularly with respect to co-ordination. Individual sub-tasks include both those performed in isolation by collective members and sub-tasks requiring interaction among collective members. The effect of these individual sub-tasks on overall collective performance will depend on their criticality and level of inter-dependence with respect to the overall collective task, and the need for information exchange and interaction with other collective members. Understanding the relationships among sub-tasks within particular collective tasks for particular collective structures is a pre-requisite of effective study of retention of collective performance, and requires selection or development of a suitable team task analysis approach.
Only one developed model of collective skill retention was found as a result of the literature search. This model was reviewed in conjunction with other models related to retention of individual skills. The conclusion was drawn that while these models form a good conceptual point of departure, none are broad enough in scope in terms of the factors covered or sufficiently well validated to serve as a satisfactory foundation for predicting retention of collective performance. Particular areas of omission included transfer from other training during the retention interval, experience of team members, internal turbulence and external turnover, and shared team mental models.
The term "collective" was rarely found in the literature on training and its use appears to add little to terms such as team and organisation, already in common use. It is recommended that the literature on team and organisational issues be more thoroughly reviewed with respect to the issues contained in this report. In particular, the literature on team mental models should be considered in greater detail in relation to retention issues, including retention of knowledge contributing to team performance.
To fulfil the global goal of developing an effective decision support tool for unit planners and modelling retention of team performance under conditions typical of military training, a longitudinal study of a small number of contrasting collectives and collective tasks is recommended. This should be based on analysis of both the needs of unit training planners and the team tasks involved in the collective tasks chosen.

(U) Il est crucial d'offrir le bon degré de formation, et il faut donc une base scientifique pour l'établissement des calendriers des cours de recyclage ou de maintien. Il existe certains écrits scientifiques sur l'établissement de calendriers pour la formation individuelle portant sur des tâches procédurales, mais les FC fonctionnent au niveau organisationnel, en faisant appel à une technologie toujours plus perfectionnée et en accordant de plus en plus d'importance aux tâches cognitives. Cet article passe en revue les données et théories publiées et non publiées provenant du milieu de la recherche et du développement militaires et portant sur la préservation des compétences collectives et cognitives en tant qu'étape menant à la proposition d'un modèle validé de maintien des compétences collectives et cognitives. On a consulté des sources électroniques et un groupe international de scientifiques en vue d'identifier les données disponibles pour la recension. L'analyse de la documentation sélectionnée a révélé l'existence de cinq facteurs : les variables des tâches, la structure du collectif, les membres du collectif, les différences individuelles et la formation. On n'a relevé qu'un modèle détaillé de maintien de compétences collectives. Ce modèle a été analysé de pair avec d'autres modèles associés au maintien de compétences individuelles. Aucun n'a une portée suffisamment vaste en

termes de facteurs pris en compte ou n'est suffisamment validé pour servir de fondement à la prévision du maintien du rendement collectif. Un plan d'élaboration d'un modèle de maintien des compétences collectives est proposé.

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U) skill retention; skill fade; training